EFFICIENCY OF DIRECT CURRENT MOTORS & GENERATORS

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ARMOUR INSTITUTE OF TECHNOLOGY

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COMPARISON OF THE VARIOUS METHODS OF DETERMINING THE COMMERCIAL EFFICIENCY OF DIRECT CURRENT MOTORS & GENERATORS

A THESIS

PRESENTED BY

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PREFACE.

In this thesis we have endeavored to make a comparison between the various methods of obtaining the commercial efficiency of direct current machines. This was accomplished by making tests on the Holtzer Cabot set in the Dynamo Laboratory of the Armour Institute of Technology. This set consists of the two direct current, direct connected, 110 volt, 45.5 amperes, 1,800 R.P.M. machines #16,880 and #16,881. For the methods of running these tests we consulted the various references given in the bibliography.

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PART 1.

INTRODUCTION.

Commercial efficiency is expressed by the fraction obtained by dividing the machines available output by its actual input. This efficiency is an important measurement of the duty of a generator, since, in making a comparison between two machines of equal cost and equal mechanical workmanship, the one which gives the highest commercial efficiency is the most economical to the user. The reliability of this efficiency depends upon the accuracy of measuring the input and output of the machine. There are several mechanical, and as many electrical, methods of doing this.

The only mechanical method which we used was the Prony brake method. This method is sometimes called the direct method because both the input and output are measured directly. An actual load test is necessary, a brake is used with motors, and generators are generally loaded on resistances. While the measurement of electrical input or output is comparatively simple, determing the mechanical power requires a brake, a

transmission dynamometer, or similar devices which are neither easily operated nor accurate in results, even on small machines and hardly applicable for large machines. Moreover, the waste of power, unavoidable with such a test, is objectionable, and in many cases even prohibitive, because it may be quite impossible to get the necessary amount of power. The results obtained cannot be very accurate, because the losses are determined as a difference between two large and not very different quantities, the input and output. A small error in either of these may result in a considerable error in the value of the efficiency.

The electrical methods which we performed in our tests were the stray power and various opposition methods. The stray power method is an indirect one, the commercial efficiency being expressed in terms of either the input or output and the losses. The indirect method is usually employed in determining efficiencies, and by its use the separation of the losses into the separate components is made possible. This method of obtaining the efficiency from losses is not quite

accurate, for the reason that the speed does not remain constant at all loads, but may drop a few per cent between no load and full load. This method, however, is invariably adopted for determining the efficiency of generators and large motors when two machines of similar design are not available for determing the efficiency by an opposition method.

Tests for determining the efficiency without the expenditure of much energy may be conveniently performed when two machines of about the same size are available. The machines are then loaded to their full capacity on each other, no power being wasted in outside resistances, or in a Prony brake. The machines are connected mechanically and electrically, and driven so that one machine acts as a generator, the other as a motor. The motor drives the generator, while the latter supplies electric power back to the motor. This is called the opposition or the "pumping back" method of testing machines. If the machines were ideal the set would be self

contained and would require no power from the outside to drive it. In reality, the losses in both machines must be supplied either by an auxiliary motor, a booster, or by connecting the set to a source of supply. The power supplied to the set from outside covers only the losses in both machines and therein lies the economy of the method.

The methods by which two electrical machines may be run in opposition are usually classified according to the way in which the losses are supplied. Copper losses may be supplied electrically or mechanically, and the stray losses may also be supplied either electrically or mechanically. This gives four possible combinations.

(1) Copper losses supplied electrically and stray power losses supplied mechanically. (a) Blondel's Opposition Method.

(2) Copper losses supplied electrically and stray power losses supplied Electrically.
  (a) Kapp's Opposition Method.
  (b) Hutchinson's Opposition Method.

(3) Copper losses supplied mechanically and stray power losses supplied mechanically.

(a) Hopkinson's Opposition Method.

(4) Copper losses supplied mechanically and stray power losses supplied electricallly.

(a) Impracticable.

Speed readings in all tests were taken on a frequency meter connected to slip rings on armature of the machine.

PART 2.

PRONY BRAKE METHOD.

The scheme of connections for the method are as shown in the diagram on page 9 . For this test but one of the machines was used, the other being disconnected. Owing to the high speed of this machine and the excessive weight of the brakes at hand, we borrowed one from the Mechanical Department to carry out our test. We experienced some difficulty in determining the dead weight of this brake, two methods being employed. The first method was to support the brake on a knife edge and take readings of its weight. The second method was to place the brake on a pulley and then to rotate the latter uniformally by hand, first in one direction and then in the opposite direction, and to take readings of its weight in each case. One reading gave us the dead weight of the brake plus the friction and the other reading gave us the dead weight of the brake minus the friction. The sum of these readings divided by two gave us the dead weight of the brake. These two methods checked up very well.

Before commencing this test we operated the motor for about two hours under full load, in order to obtain a constant temperature in the windings. Owing to the peculiar construction of the fields it was impossible to measure the temperature by the use of thermometers, therefore, the rise in resistance was used as an indication of the temperature.

The object of this method of test was to measure the electrical power supplied to the motor and the mechanical power delivered by the motor. The electrical power supplied to the motor was numerically equal to the product of the current multiplied by the pressure measured at the terminals of the machine. The mechanical output was measured by applying a friction brake to the rim of a pulley on the motor shaft, and measuring the retarding force exerted by the brake on the pulley. By varying the pressure of the brake on the motor we regulated the load from a low value up to the full output for which the motor was designed.

Let I = current in amperes consumed by the motor.

Let E = voltage at terminals of motor.

Then input to motor = $E\ I$ watts = $\frac{E\ I}{746}$ H. P.

To determine the mechanical output of the motor, let;

L = length, in ft. of lever from center of pulley to point of support.

P' = dead weight of brake.

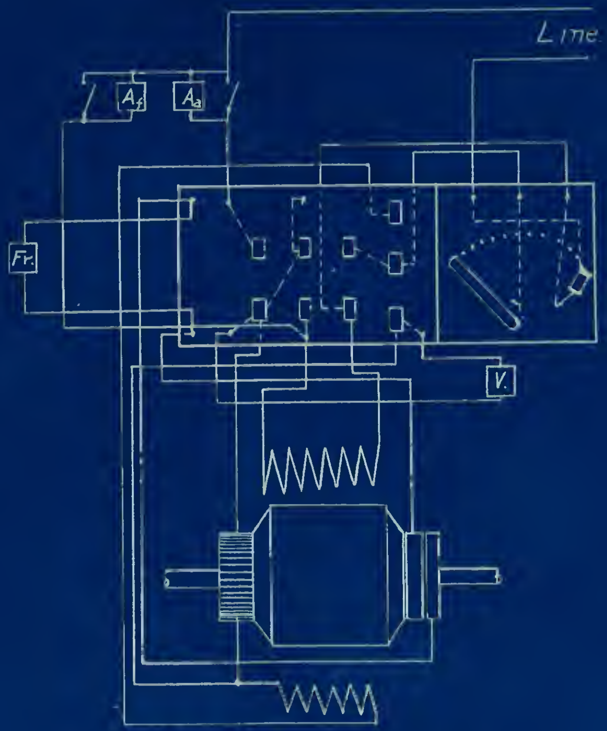
P = scale reading.

S = speed of machine in R. P. M.

Power outfit at pulley of motor therefore = $\frac{2\pi S(P-P')}{33,000}$ H.P.

The efficiency of the motor at any particular load is therefore

$$\frac{2\pi S\ (P - P')}{33,000} \times \frac{746}{E\ I}$$



Connections for Prony Brake Method.

EXPERIMENTAL DATA.

PRONY BRAKE METHOD. (Test One.) April 7, 1910.

I_f	I_a	I	E	W	S
2.16	7.3	9.46	108.8	0.0	1800
2.01	13.7	15.71	108.8	4.0	1800
2.01	15.8	17.81	108.8	4.5	1800
2.01	17.7	19.71	108.8	5.0	1800
2.01	21.0	23.01	108.8	6.0	1800
2.01	22.7	24.71	108.8	6.5	1800
2.00	25.0	27.00	108.8	7.0	1800
2.00	28.6	30.60	108.8	8.0	1800
2.00	30.0	32.00	108.8	8.5	1800
2.00	31.8	33.80	108.8	9.0	1800
2.00	35.4	37.40	108.8	10.0	1800
2.00	37.5	39.50	108.8	10.5	1800
1.98	39.5	41.48	108.8	11.0	1800
1.98	43.0	44.98	108.8	12.0	1800
1.97	44.4	46.37	108.8	12.3	1800

I_f - Field current. (corrected)

I_a - Armature .. ..

I - Total ..

E - Voltage. (corrected)

W - Gross weight.

S - Speed in r.p.m.

CALCULATED DATA.

PRONY BRAKE METHOD. (Test One.) April 7, 1910.

S	W_2	K	B.H.P.	P	E.H.P.	E
1800	0.00	.5141	0.000	1029	1.379	0.00
1800	2.72	.5141	1.408	1709	2.293	61.01
1800	3.22	.5141	1.655	1939	2.597	63.72
1800	3.72	.5141	1.912	2144	2.874	66.52
1800	4.72	.5141	2.427	2504	3.355	72.34
1800	5.22	.5141	2.684	2688	3.603	74.49
1800	5.72	.5141	2.941	2937	3.937	74.70
1800	6.72	.5141	3.455	3329	4.462	77.43
1800	7.22	.5141	3.712	3482	4.667	79.10
1800	7.72	.5141	3.969	3677	4.929	80.53
1800	8.72	.5141	4.483	4069	5.454	82.19
1800	9.22	.5141	4.740	4298	5.760	82.29
1800	9.72	.5141	4.997	4514	6.051	82.58
1800	10.72	.5141	5.511	4894	6.560	84.09
1800	11.02	.5141	5.665	5045	6.762	83.77

S - Speed in r.p.m.

W_2 - Net weight.

K -(6.2832 L S) divided by (33000)

B.H.P.- K multiplied by W_2

P - Watts input.

E.H.P.- P divided by 746

E - Commerical efficiency.

EXPERIMENTAL DATA.

PRONY BRAKE METHOD. (Test Two.) April 7, 1910.

I_f	I_a	I	E	W	S
2.16	7.3	9.46	108.8	0.0	1800
2.01	15.8	17.81	108.8	4.5	1800
2.01	17.7	19.71	108.8	5.0	1800
2.01	20.7	22.71	108.8	6.0	1800
2.01	22.6	24.61	108.8	6.5	1800
2.01	24.5	26.51	108.8	7.0	1800
2.01	28.0	30.01	108.8	8.0	1800
2.00	30.0	32.00	108.8	8.5	1800
2.00	32.4	34.40	108.8	9.0	1800
2.00	35.5	37.50	108.8	10.0	1800
2.00	37.8	39.80	108.8	10.5	1800
2.00	39.9	41.90	108.8	11.0	1800
2.00	42.9	44.90	108.8	12.0	1800
2.00	44.5	46.50	108.8	12.3	1800

I_f - Field current. (corrected)

I_a - Armature .. ..

I - Total ..

E - Voltage. (corrected)

W - Gross weight.

S - Speed in r.p.m.

CALCULATED DATA.

PRONY BRAKE METHOD. (Test Two.) April 7, 1910.

S	W_2	K	B.H.P.	P	E.H.P.	E
1800	0.00	.5141	0.000	1029	1.379	0.00
1800	3.22	.5141	1.655	1938	2.597	63.72
1800	3.72	.5141	1.912	2144	2.874	66.52
1800	4.72	.5141	2.427	2469	3.310	73.02
1800	5.22	.5141	2.684	2677	3.587	74.82
1800	5.72	.5141	2.941	2883	3.864	76.11
1800	6.72	.5141	3.455	3264	4.375	78.97
1800	7.22	.5141	3.712	3481	4.667	79.53
1800	7.72	.5141	3.969	3742	5.017	79.11
1800	8.72	.5141	4.483	4080	5.469	81.96
1800	9.22	.5141	4.740	4230	5.670	83.59
1800	9.72	.5141	4.997	4558	6.110	81.78
1800	10.72	.5141	5.511	4885	6.548	84.16
1800	11.02	.5141	5.665	5069	6.795	83.35

S - Speed in r.p.m.

W_2 - Net weight.

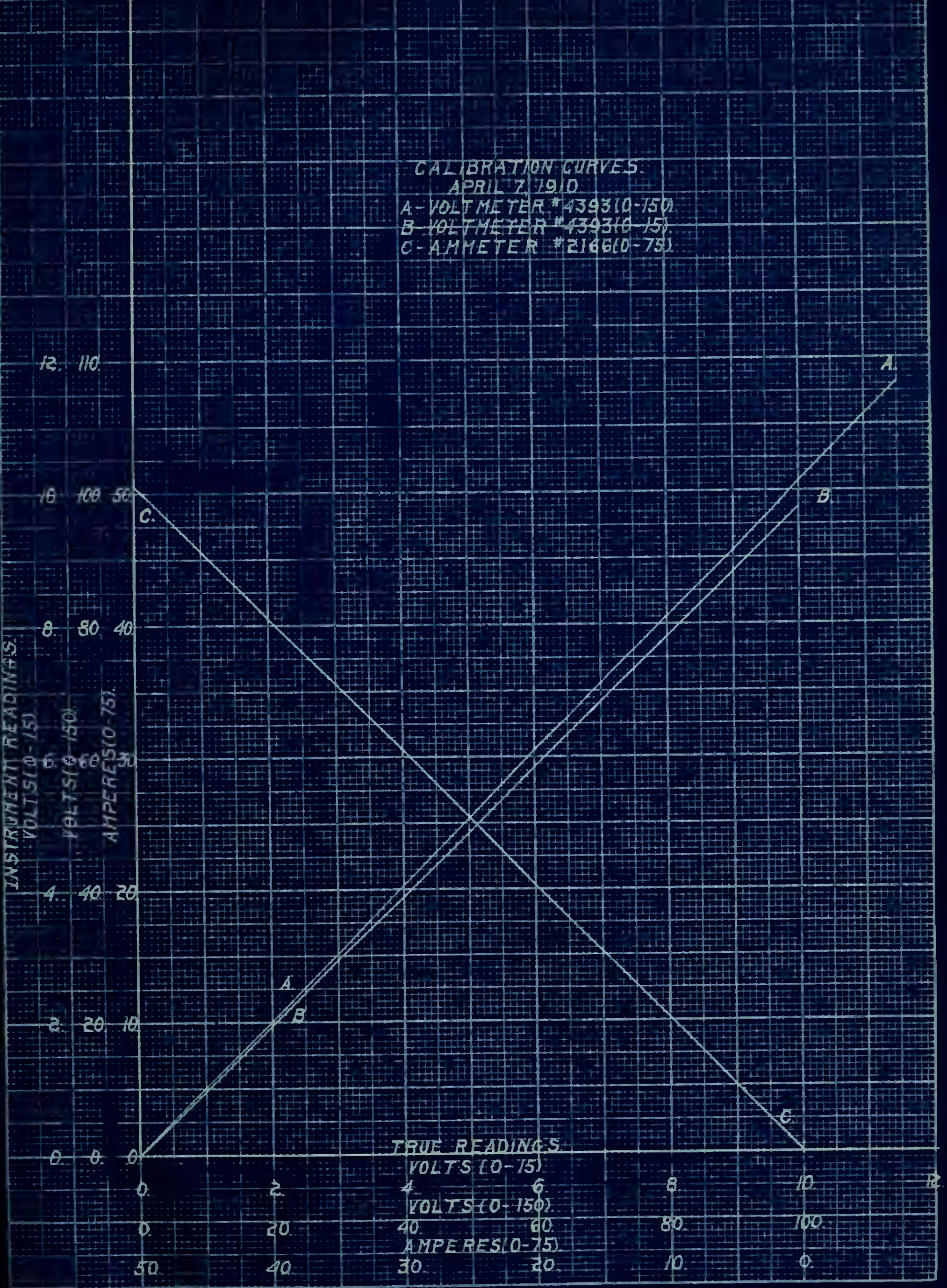
K = (6.2832 LS) divided by (33000)

B.H.P.-K multiplied by W_2

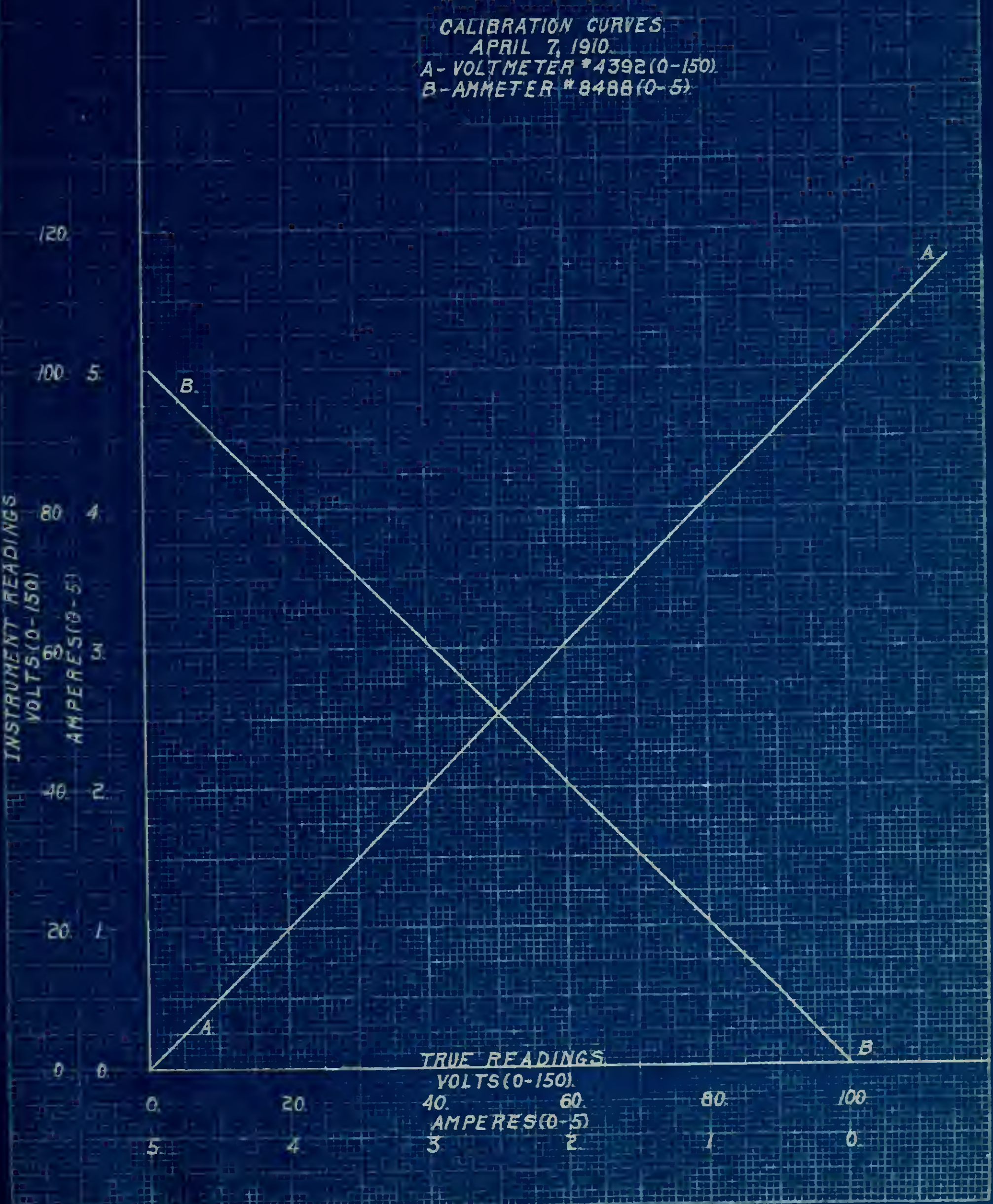
P - Watts input.

E.H.P.-P divided by 746

E - Commerical efficiency.



EUGENE DIETZGEN CO., CHICAGO.


CALIBRATION CURVES
APRIL 7, 1910.
A- VOLTMETER #4392 (0-150).
B- AMMETER #8488 (0-5).

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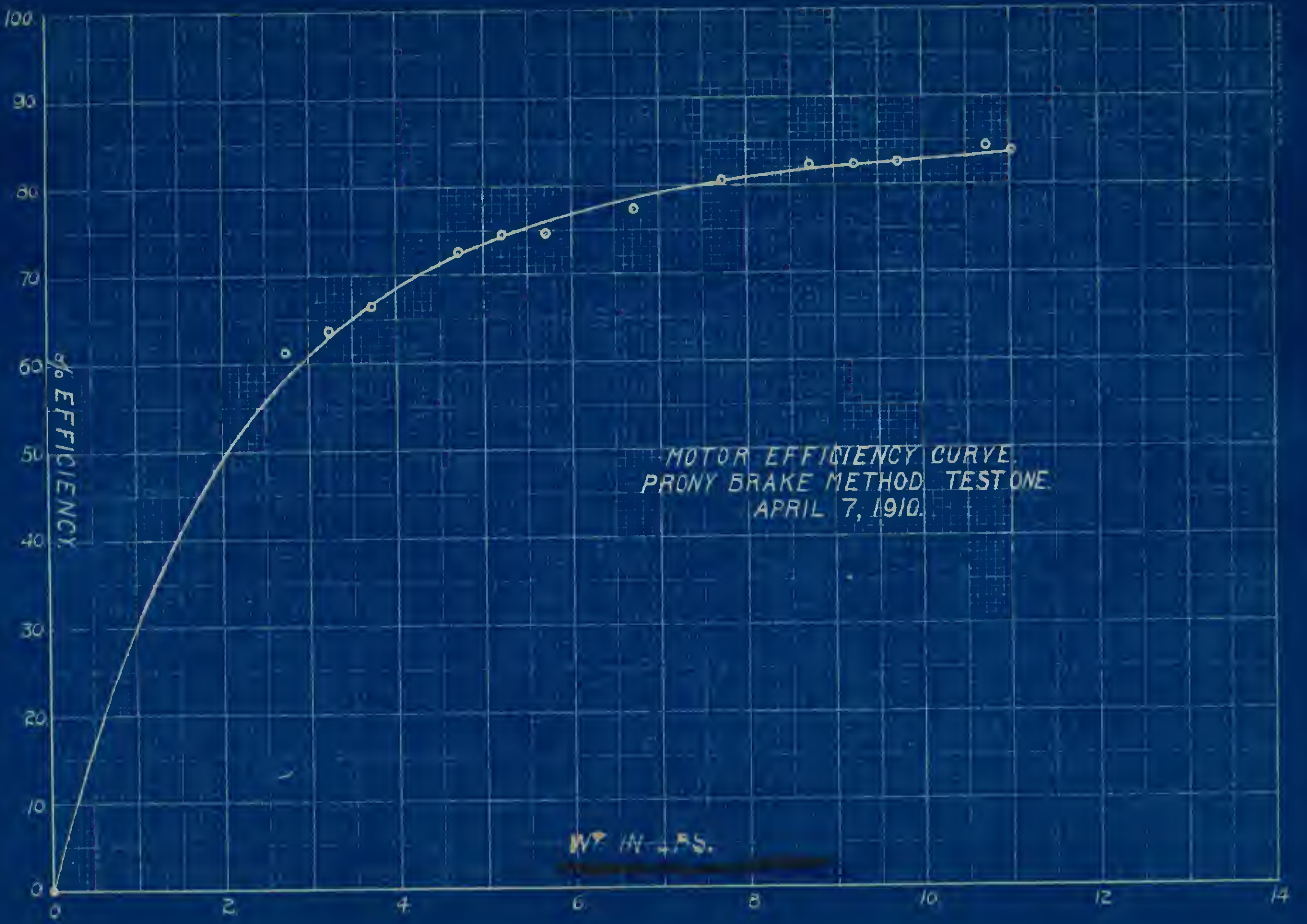
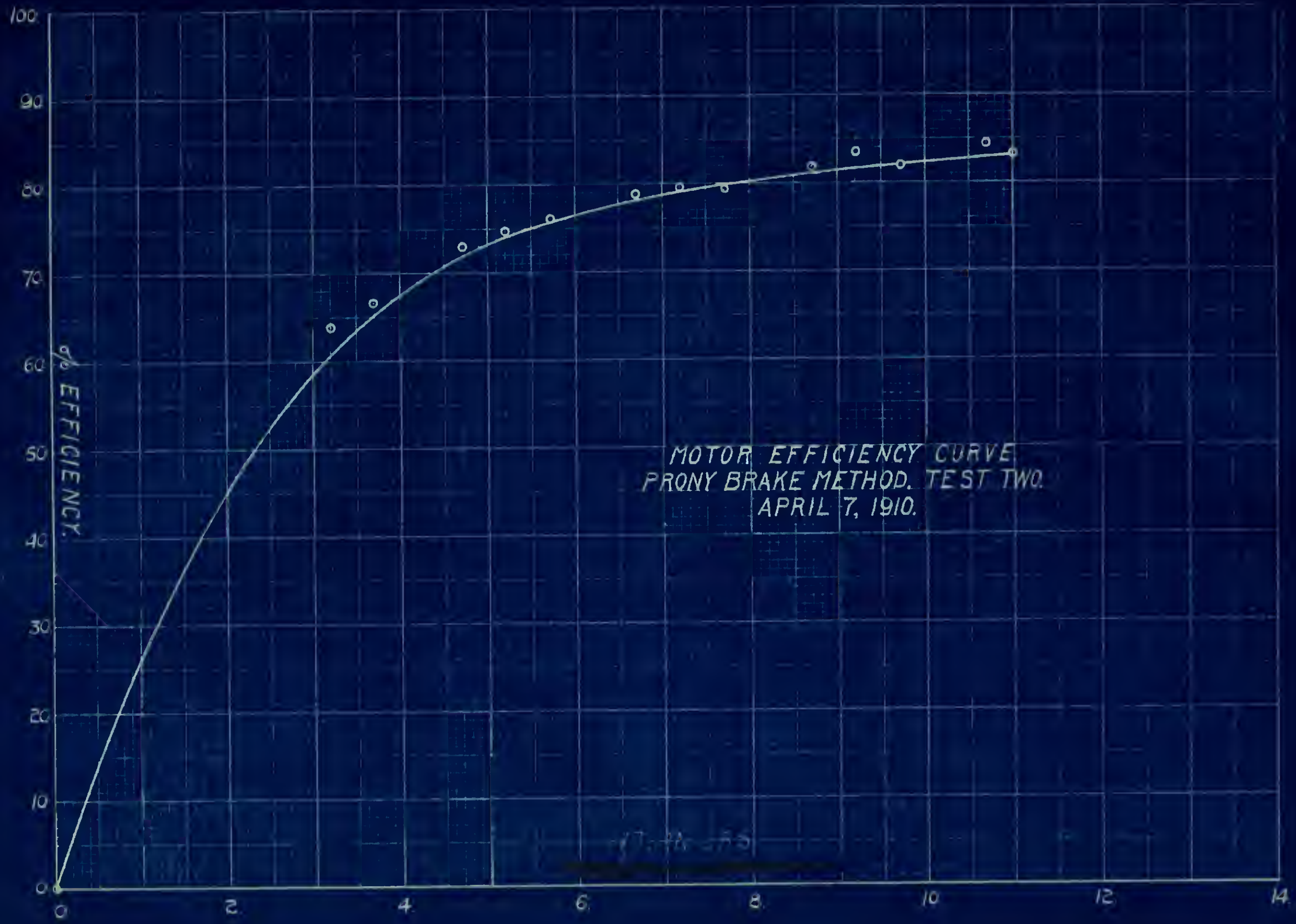


MOTOR EFFICIENCY CURVE.
PRONY BRAKE METHOD. TEST ONE.
APRIL 7, 1910.


MOTOR EFFICIENCY CURVE
PRONY BRAKE METHOD. TEST TWO.
APRIL 7, 1910.

PART 3.

STRAY POWER METHOD.

The scheme of connections for this method are as shown in the diagram on page 20 . This method consists of measuring the various losses separatoly. These losses are the copper loss and stray power loss. The stray power loss is the power expended in turning the armature of a generator or a motor, when the field is excited and there is no current in the armature winding. Before commencing this test we operated the set for about two hours under full load in order to obtain a constant temperature in the windings.

In order to find the range of stray power loss with load we proceeded in the following manner. We operated one of the machines as a motor at constant normal speed and no load, impressing upon its terminals a range of voltages and taking readings of input. Since the counter electro motive force varies as the load a curve showing the variation of stray power loss with counter electro motive force was plotted from the above readings. This curve is shown on page 30 .

The stray power loss was calculated from the equation.

$$W_s = EI - I^2R.$$

where W_s = stray power loss in motor or generator

E = Terminal voltage.

I = Armature current.

R = Armature resistance.

For calculating the commercial efficiency of the motor we used the following equation.

$$\text{Com. Eff.} = \frac{EI - (I_a^2R_a + I_f^2R_f + W_s)}{EI}$$

For calculating the commercial efficiency of the generator we used the following equation.

$$\text{Com. Eff.} = \frac{EI}{EI + (I_a^2R_a + I_f^2R_f + W_s)}$$

Where E = terminal voltage.

I = Total current.

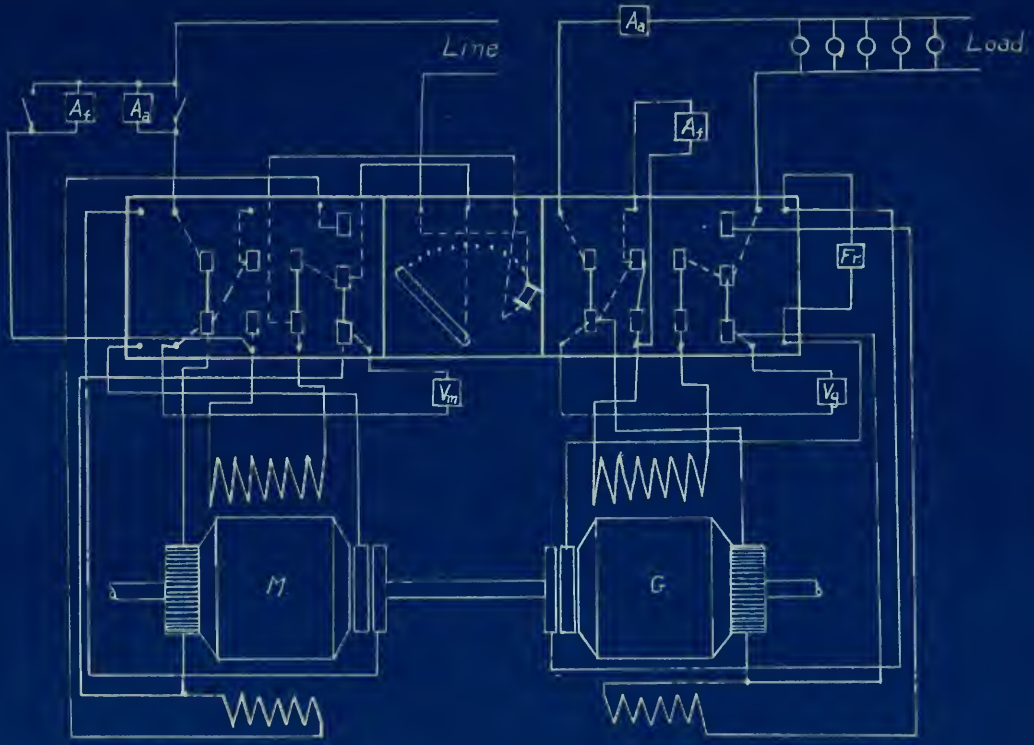
I_a = Armature current.

I_f = Field current.

R_a = Armature resistance.

R_f = Field resistance.

W_s = Stray power loss.



Connections for Stray Power Method.

Determination of Stray Power Loss. April 8, 1910.

E	I	EI	I^2R	W_s	S
88.8	7.0	621.6	5.68	615.9	1800
90.8	7.0	635.6	5.68	629.9	1800
92.7	7.0	648.9	5.68	643.2	1800
94.8	7.0	663.6	5.68	657.9	1800
96.8	7.0	677.6	5.68	671.9	1800
98.9	7.0	692.3	5.68	686.6	1800
100.8	7.0	705.6	5.68	699.9	1800
102.7	7.0	718.9	5.68	713.2	1800
104.8	7.0	733.3	5.68	727.6	1800
106.8	7.0	747.6	5.68	741.9	1800
108.7	7.0	760.9	5.68	758.1	1800

E - Voltage.

I - Armature current.

R - .. resistance.

W_s - Stray power loss.

EXPERIMENTAL DATA.

STRAY POWER METHOD. (Test One.) April 8, 1910.

S	I_a	I_f	E	I'_a	I'_f	E'
1800	11.1	2.07	108.7	0.0	0.00	00.0
1800	17.9	2.04	108.7	6.9	1.34	86.7
1800	24.8	2.02	108.7	7.4	1.96	104.8
1800	27.2	2.00	108.7	12.1	1.95	104.5
1800	33.7	1.99	108.7	17.7	1.93	104.0
1800	37.9	1.99	108.7	22.6	1.94	103.8
1800	42.3	1.98	108.7	27.3	1.93	103.5
1800	46.9	1.98	108.7	31.4	1.92	102.9
1800	52.4	1.97	108.7	37.2	1.90	102.0
1800	57.0	1.95	108.7	41.7	1.90	102.0

S - Speed in r.p.m.

I_a - Armature current of motor.

I'_a - .. .. ..generator.

I_f - Field .. .. motor.

I'_f - .. .. .. generator.

E - Voltage of motor.

E' - .. .. generator.

CALCULATED DATA.

STRAY POWER METHOD. (Test One.) April 8, 1910.

I_a	E	E'	W_s	EI	$I_a^2R_a$	EI_f	E_m
11.13	108.7	107.4	747.3	1435	14.3	225.0	31.12
17.86	108.7	106.7	741.9	2163	37.2	221.7	53.80
22.78	108.7	106.1	736.9	2696	60.3	219.6	62.35
27.20	108.7	105.5	733.1	3174	85.8	217.4	67.50
33.70	108.7	104.8	728.1	3783	131.7	216.6	69.90
37.91	108.7	104.3	724.6	4337	166.6	216.3	74.65
42.32	108.7	103.8	721.3	4815	207.5	216.2	76.25
46.92	108.7	103.3	717.5	5305	255.2	215.2	77.81
52.43	108.7	102.6	712.1	5913	318.5	214.1	78.84
57.05	108.7	102.1	708.8	6413	376.8	211.9	79.90

I_a - Armature current of motor.

E - External voltage.

E' - Internal ..

W_s - Stray power loss of motor.

EI - power taken by motor.

$I_a^2R_a$ - Copper loss in armature.

EI_f - Field loss.

E_m - Commerical efficiency of the motor.

CALCULATED DATA.

STRAY POWER METHOD. (Test One.) April 8, 1910.

I_a	E	E'	W_s	EI	$I_t^2R_a$	EI_f	E_g
0.0	0.0	0.0	0.0	0	0.0	0.0	0.0
6.9	86.7	87.6	607.5	714	7.6	85.2	50.55
7.4	104.8	105.9	736.2	981	9.9	182.3	51.35
12.1	104.5	106.1	736.4	1468	22.1	180.5	61.00
17.7	104.0	106.2	737.9	2042	43.6	176.8	68.05
22.6	103.8	106.6	740.4	2547	68.4	178.6	72.05
27.3	103.5	106.8	742.4	3025	96.3	176.8	74.85
31.4	102.9	106.7	741.3	3429	125.3	175.0	76.75
37.2	102.0	106.4	738.4	3988	172.8	171.3	78.70
41.7	102.0	106.9	743.2	4447	214.7	171.3	79.85

I_a - Armature current of generator .

E - External voltage.

E'- Internal ..

W_s - Stray power loss of generator.

EI - Power taken by generator.

$I_t^2R_a$ - Copper loss in armature.

EI_f - Field loss.

E_g - Commerical efficiency of the generator.

EXPERIMENTAL DATA.

STRAY POWER METHOD. (Test Two.) April 8, 1910.

S	I_a	I_f	E	I'_a	I'_f	E'
1800	11.1	2.07	108.7	0.0	0.00	00.0
1800	18.4	2.04	108.7	6.8	1.32	86.4
1800	22.3	2.04	108.7	7.4	1.94	104.6
1800	26.8	2.01	108.7	12.1	1.93	104.3
1800	32.3	2.02	108.7	17.7	1.92	103.8
1800	38.0	2.01	108.7	23.4	1.91	102.9
1800	42.3	2.00	108.7	27.3	1.92	103.0
1800	47.8	2.00	108.7	32.6	1.91	102.0
1800	52.8	1.98	108.7	37.2	1.90	102.0
1800	57.0	1.95	108.7	41.7	1.90	102.0

S - Speed in r.p.m.

I_a - Armature current of motor.

I'_a - .. .. .. generator.

I_f - Field .. .. motor.

I'_f - .. .. .. generator.

E - Voltage of motor.

E' - .. .. generator.

CALCULATED DATA.

STRAY POWER METHOD. (Test Two.) April 8, 1910.

I_a	E	E'	W_s	EI	$I_a^2R_a$	EI_f	E_m
11.23	108.7	107.4	747.3	1446	14.5	225.0	31.08
18.36	108.7	106.6	740.6	2217	39.2	221.7	54.85
22.26	108.7	106.1	737.2	2642	55.6	221.7	61.55
26.79	108.7	105.6	734.1	3122	83.3	218.5	66.70
32.28	108.7	105.0	729.3	3728	121.0	219.6	71.25
38.00	108.7	104.3	724.6	4359	167.5	218.5	74.56
42.30	108.7	103.8	721.3	4815	207.0	217.4	75.00
47.80	108.7	103.2	715.6	5313	265.0	217.4	77.45
52.22	108.7	102.7	712.4	5892	316.0	215.2	78.85
57.05	108.7	102.1	708.8	6413	376.8	211.9	79.90

I_a - Armature current of motor.

E - External voltage.

E' - Internal ..

W_s - Stray power loss of motor.

EI - Power taken by motor.

$I_a^2 R_a$ - Copper loss in armature.

EI_f - Field loss.

E_m - Commerical efficiency of the motor.

CALCULATED DATA.

STRAY POWER METHOD. (Test Two.) April 8, 1910.

I_a	E	E'	W_s	EI	$I_t^2R_a$	EI_f	E_g
0.0	0.0	0.0	0.0	0	0.0	0.0	0.0
6.8	86.4	87.3	605.0	702	7.4	82.7	50.30
7.4	104.6	105.7	734.4	977	9.8	178.6	51.35
12.1	104.6	105.9	736.2	1463	22.1	176.8	61.15
17.7	103.8	106.0	736.0	2036	43.4	175.0	68.05
23.4	102.9	105.8	735.7	2604	72.3	173.1	72.65
27.3	103.0	106.2	737.9	3010	96.4	175.0	76.05
32.6	102.0	105.9	736.2	3520	134.5	173.1	77.30
37.2	102.0	106.4	739.6	3988	172.8	171.3	78.70
41.7	102.0	106.9	743.2	4447	214.7	171.3	79.85

I_a - Armature current of generator.

E - External voltage.

E' - Internal ..

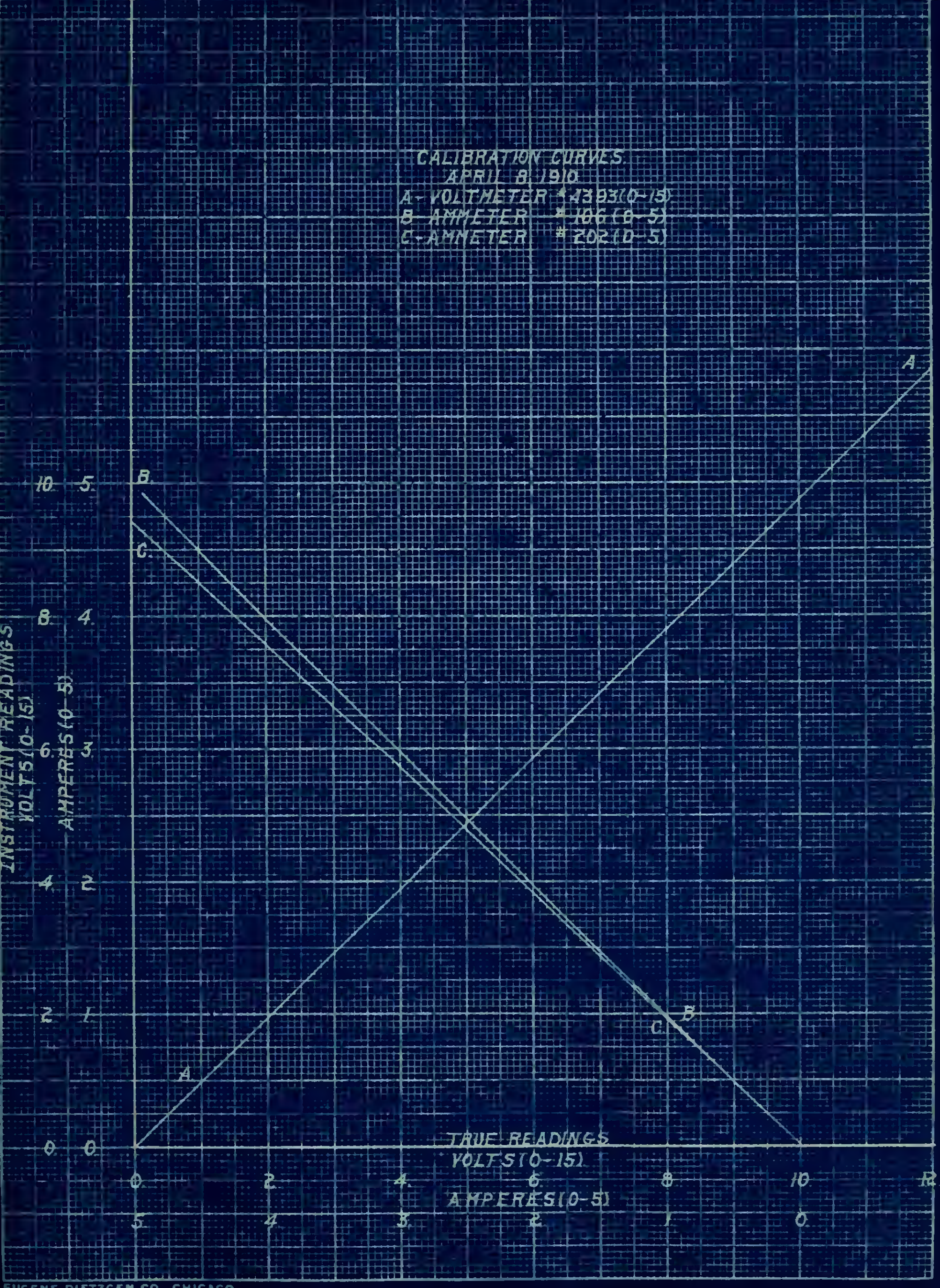
W_s - Stray power loss of generator.

EI - Power taken by generator.

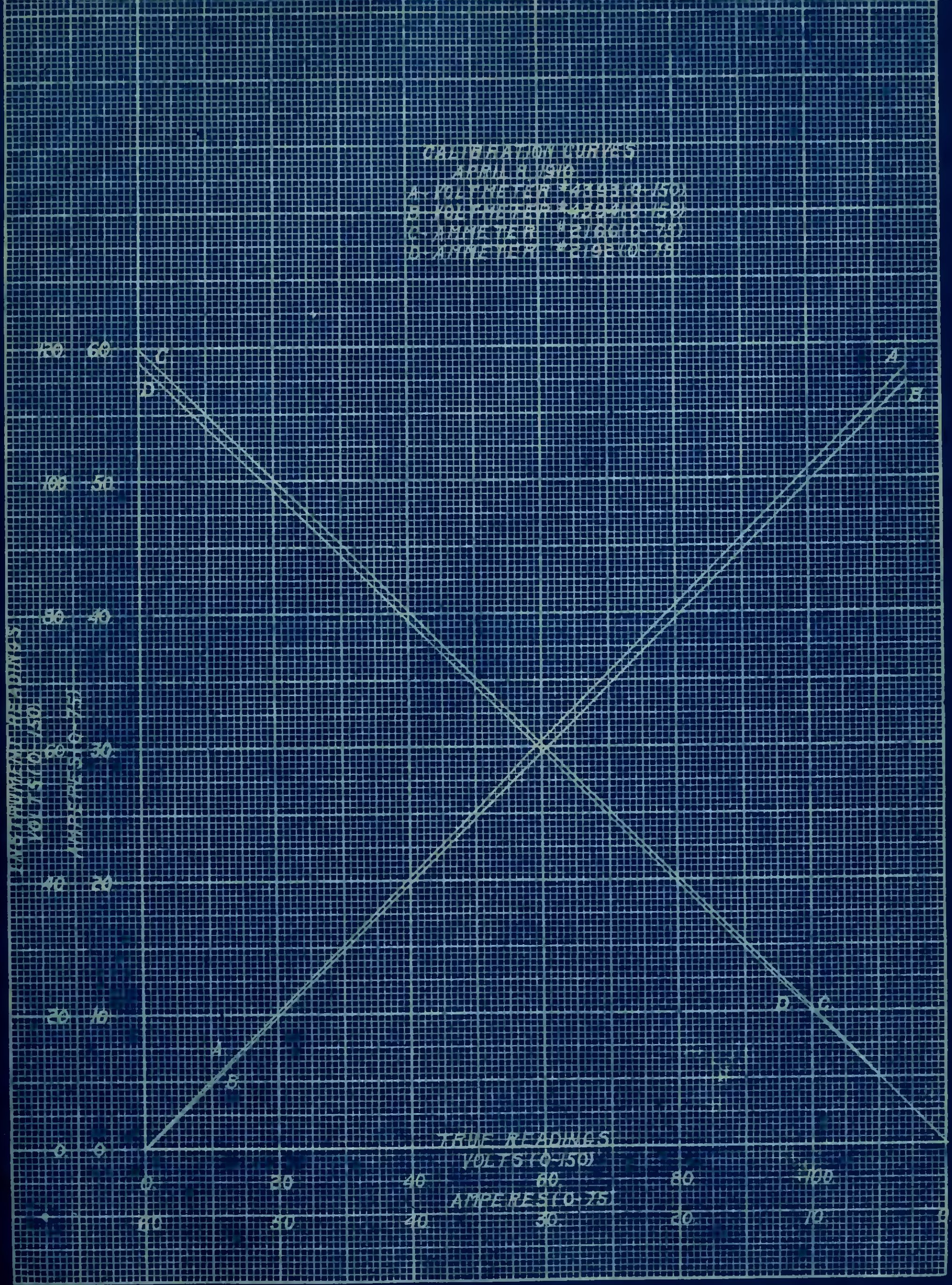
$I_t^2R_a$ - Copper loss in armature.

EI_f - Field loss.

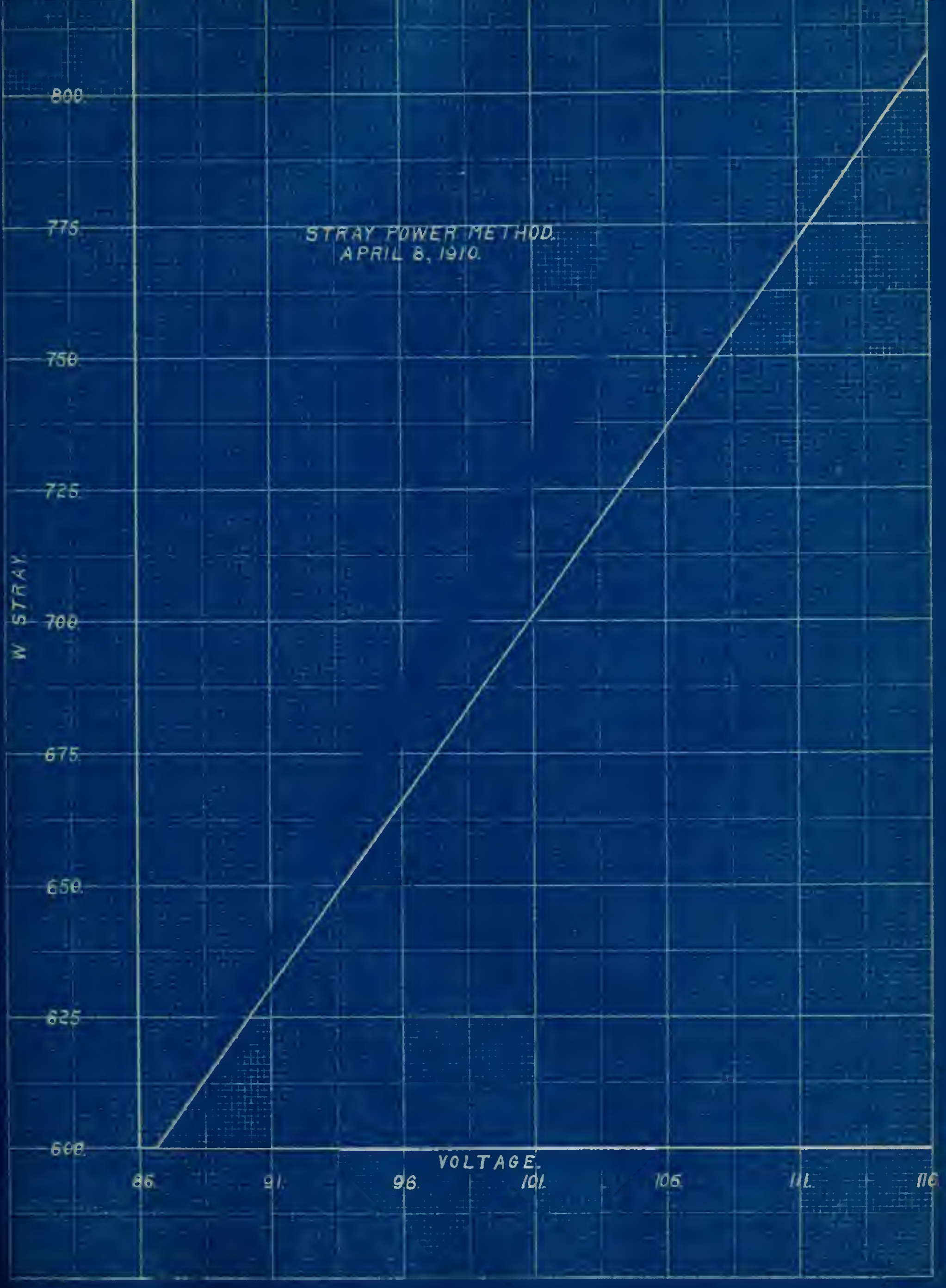
E_g - Commerical efficiency of the generator.


CALIBRATION CURVES.
APRIL 8 1910
A-VOLTMETER #4393(0-15)
B-AMMETER #106 (0-5)
C-AMMETER #202(0-5)

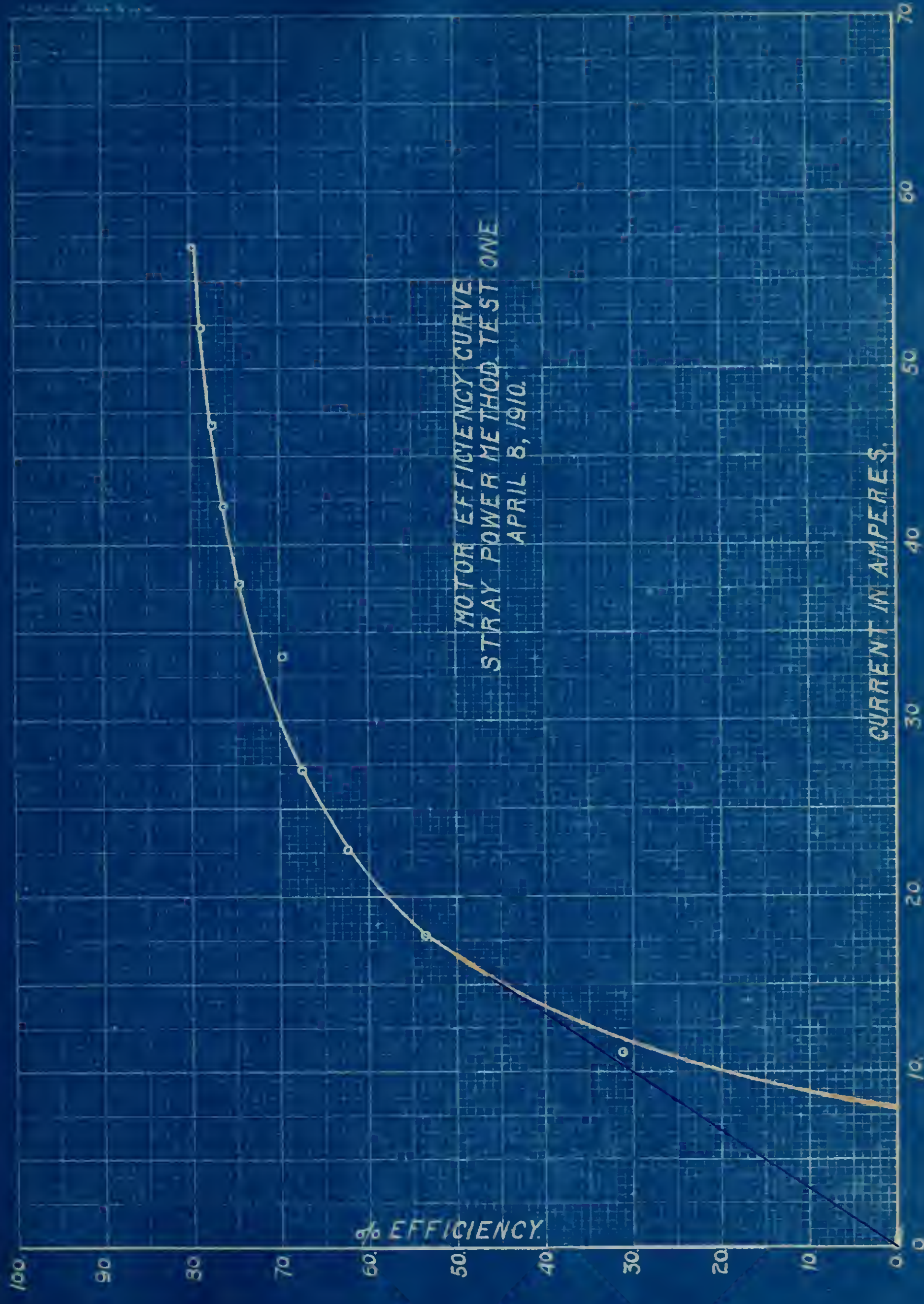
EUGENE DIETZGEN CO., CHICAGO.

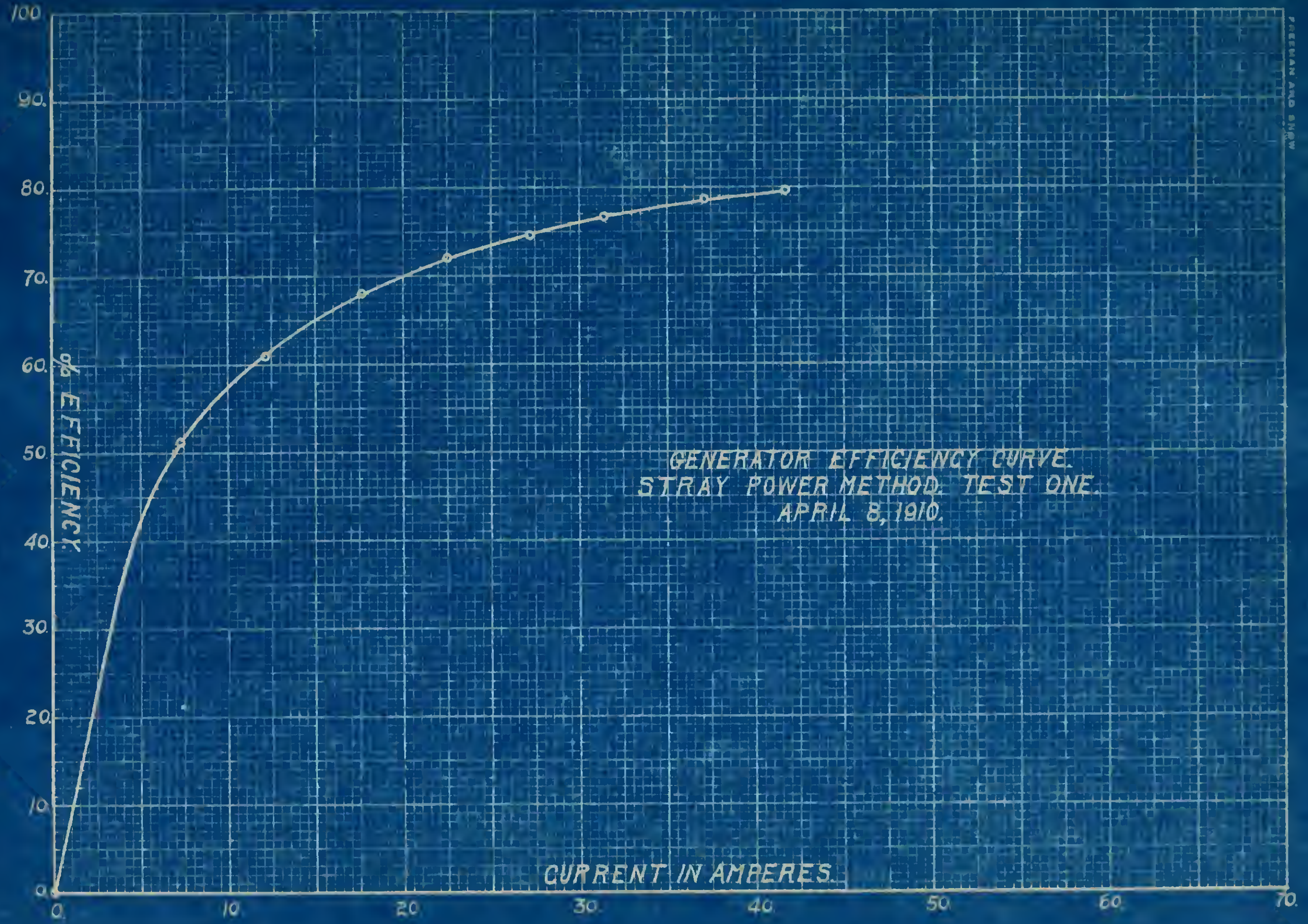


EUGENE DIETZGEN CO., CHICAGO.

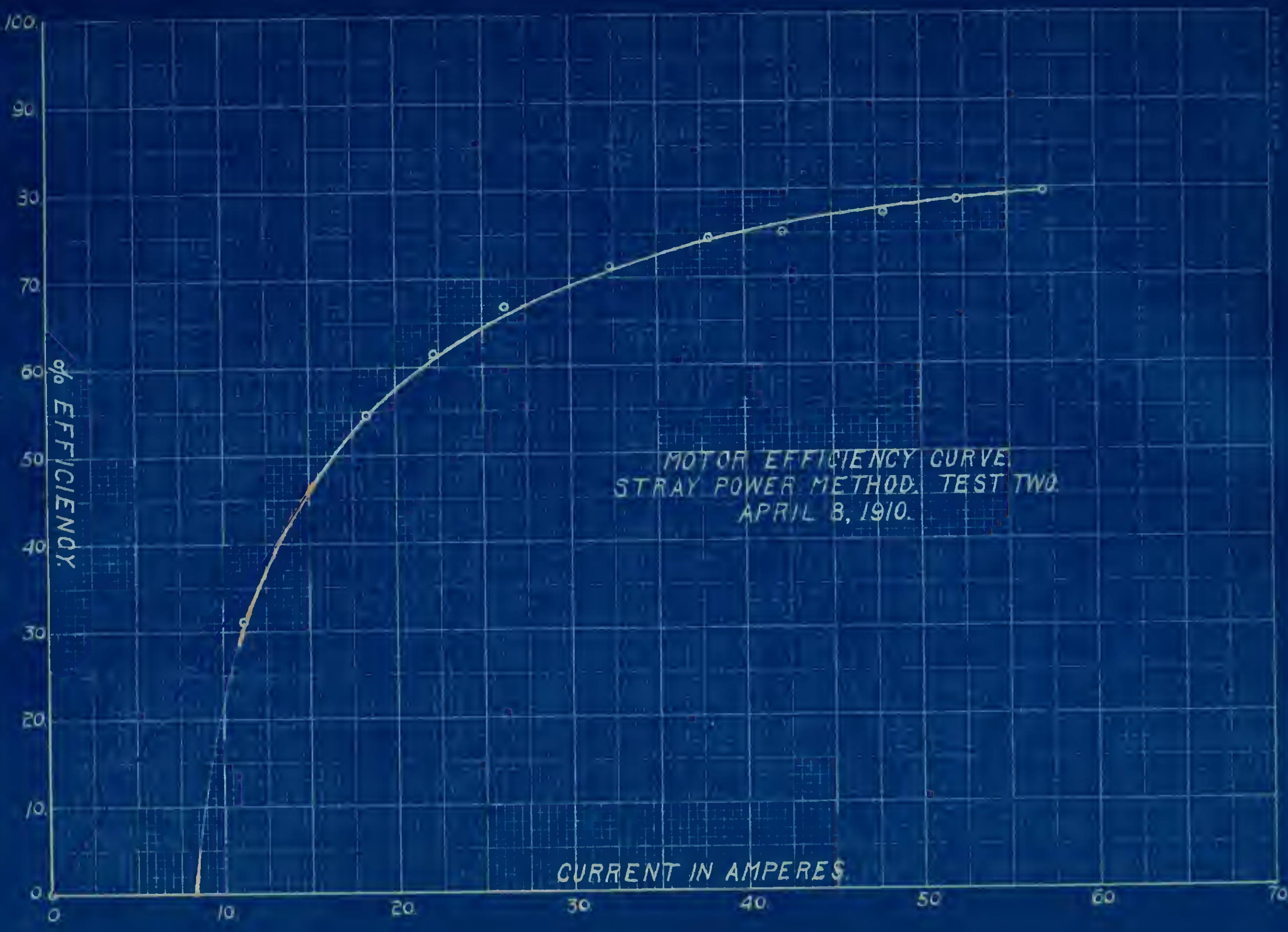


STRAY POWER METHOD.
APRIL 8, 1910.

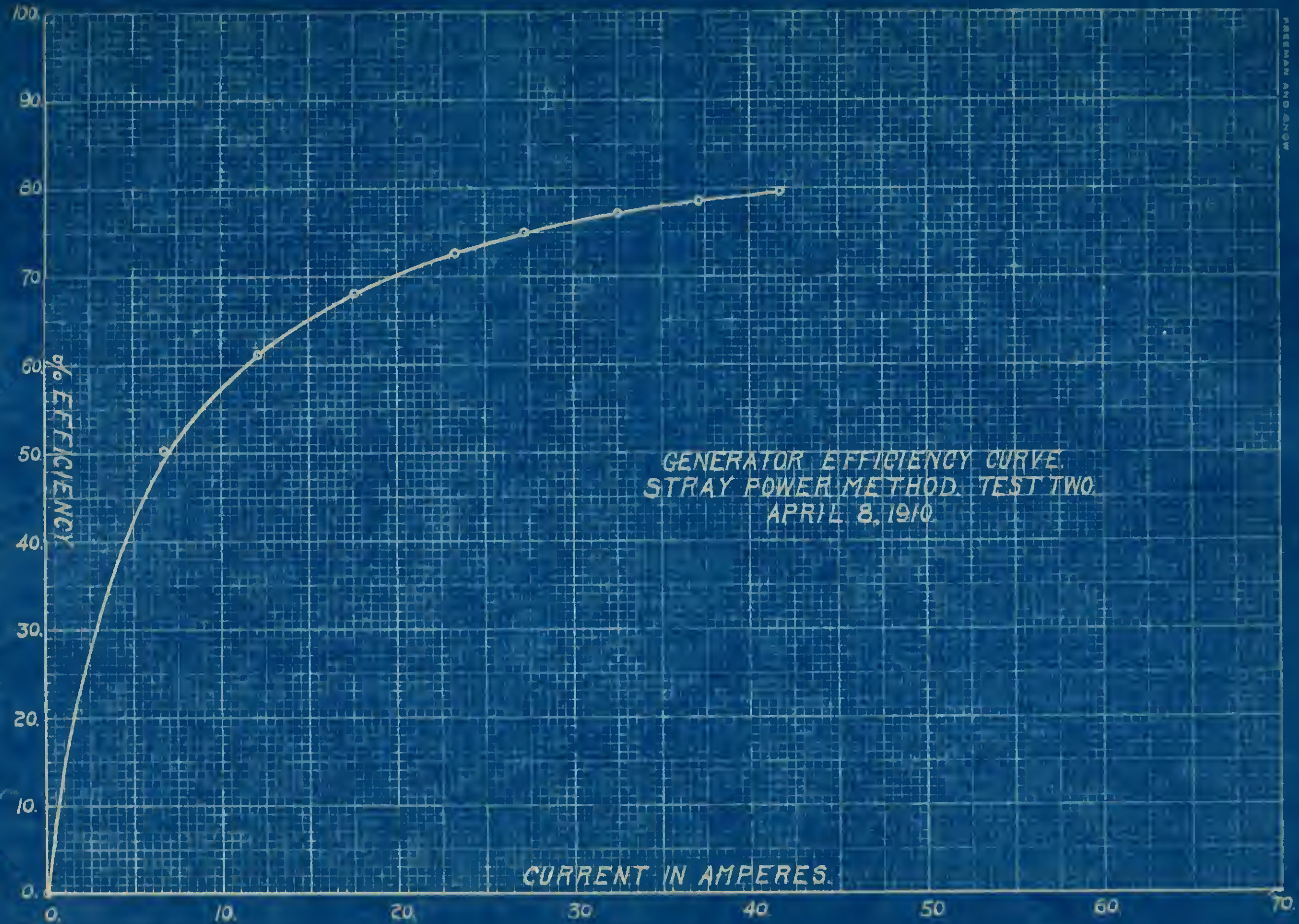

MOTOR EFFICIENCY CURVE
STRAY POWER METHOD TEST ONE
APRIL 8, 1910.
CURRENT IN AMPERES.
% EFFICIENCY.
0
10
20
30
40
50
60
70
0.
10
20.
30.
40
50.
60.
70
80
90
100



GENERATOR EFFICIENCY CURVE.
STRAY POWER METHOD. TEST ONE.
APRIL 8, 1910.



MOTOR EFFICIENCY CURVE
STRAY POWER METHOD. TEST TWO.
APRIL 8, 1910.



GENERATOR EFFICIENCY CURVE.
STRAY POWER METHOD. TEST TWO.
APRIL 8, 1910.

PART 4.

KAPP'S OPPOSITION METHOD.

The scheme of connections for this method are as shown in the diagram on page 37. In this test both machines were mechanically and electrically connected. One machine was used as a motor to start the set in motion and to bring it up to speed. The voltage of the generator was then made equal to and opposite that of the motor and the electrical connection between the two machines closed. After the adjustment was made and the switch closed an interchange of power between the two machines was brought about by weakening the motor field and strengthening that of the generator. In this case the motor tended to speed up and drive the generator mechanically; the latter, in turn, having the higher pressure, drove the motor electrically. By varying the field rheostats on both machines we obtained a range of loads from zero to full load.

In this test the assumption that the losses of the two machines are equal is incorrect inasmuch as the motor load is heavier than that of

the generator, hence the losses of the former are greater than those of the latter. The result is the efficiency of the generator is slightly lower than it should be and that of the motor is slightly higher.

For calculating the commercial efficiency of the motor we used the following equation.

$$\text{Com. Eff.} = \frac{E\,I' - 1/2\,W_p}{E\,I'}$$

For calculating the commercial efficiency of the generator we used the following equation.

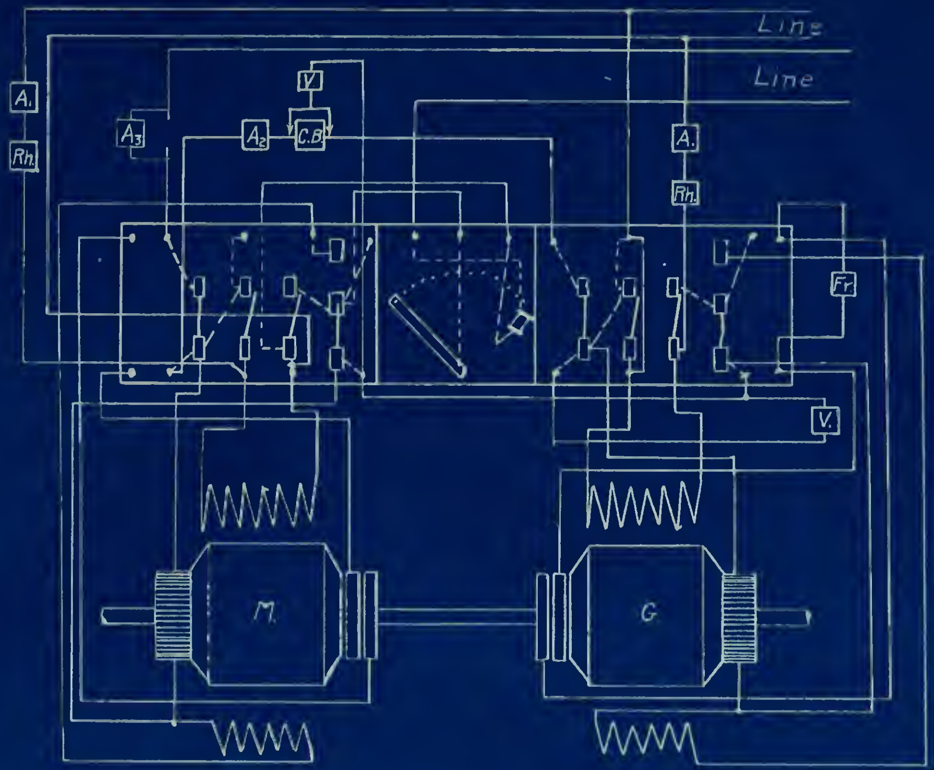
$$\text{Com. Eff.} = \frac{E\,I}{E\,I + 1/2\,W_p}$$

where E = terminal voltage.

I' = current flowing between the machines plus the loss supplier current.

I = current flowing between the machines.

W_p = power supplied by the loss supplier.



Connections for Kapp's Opposition Method.

EXPERIMENTAL DATA.

KAPP'S OPPOSITION METHOD. (Test One.) April 15, 1910.

V_m	I_m	I'_m	V_g	I_g	I'_g	S
112.0	9.90	2.22	0.0	0.00	0.00	1800
110.5	14.40	2.11	111.6	5.00	2.30	1800
111.5	14.90	2.13	113.4	10.70	2.38	1800
111.5	15.50	2.12	112.8	16.20	2.42	1800
112.0	16.00	2.17	114.0	21.30	2.53	1800
111.5	16.50	2.11	113.4	26.30	2.48	1800
111.5	17.50	2.11	113.4	30.50	2.53	1800
112.5	18.50	2.10	114.3	37.30	2.57	1800
113.0	19.00	2.07	115.0	41.40	2.65	1800
113.0	19.50	2.10	114.6	46.10	2.66	1800
112.5	20.50	2.10	114.6	51.40	2.67	1800
112.5	21.25	2.10	114.6	56.20	2.72	1800
113.0	22.5	2.10	115.2	61.20	2.78	1800

V_m - Motor voltage.

V_g - Generator voltage.

I_m - ~~Total motor~~ current.

I'_m - Field .. ..

I_g - Armature generator current.

I'_g - Field .. ..

S - Speed in r.p.m.

CALCULATED DATA.

KAPP'S OPPOSITION METHOD. (Test One.) April 15, 1910.

S	I_m	W_p	I_g	EI	E_g	E_m
1800	9.90	1108	00.0	0000	00.00	00.00
1800	14.40	1592	5.0	812	54.25	66.70
1800	14.90	1662	10.7	1479	63.06	73.55
1800	15.50	1728	16.2	2097	70.82	77.45
1800	16.00	1792	21.3	2712	75.11	79.90
1800	16.50	1840	26.3	3259	77.74	81.97
1800	17.50	1952	30.8	3775	79.22	83.05
1800	18.50	2082	37.3	4553	81.39	84.45
1800	19.00	2148	41.4	5060	82.93	85.15
1800	19.50	2204	46.1	5586	83.52	85.80
1800	20.50	2306	51.4	6191	84.45	86.76
1800	21.25	2392	56.2	6747	84.81	86.90
1800	22.50	2542	61.2	7364	85.28	87.16

S - Speed in r.p.m.

I_m - ~~Total motor~~ current.

I_g - Armature generator current.

W_p - Power taken by motor from line.

EI - Power from the generator.

E_g - Commerical efficiency of the generator.

E_m - .. .. motor.

I' = [illegible] = I_g + [illegible]

EXPERIMENTAL DATA.

KAPP'S OPPOSITION METHOD. (Test Two.) April 15, 1910.

V_m	I_m	I'_m	V_g	I_g	I'_g	S
112.0	9.90	2.22	0.0	0.0	0.00	1800
111.5	14.90	2.11	113.0	7.4	2.34	1800
110.0	15.25	2.03	111.8	11.4	2.27	1800
109.5	15.50	1.97	111.0	17.7	2.27	1800
109.0	16.00	1.96	110.8	22.5	2.27	1800
109.0	16.50	1.95	110.8	25.9	2.58	1800
108.5	17.00	1.92	110.3	31.8	2.60	1800
109.0	17.75	1.88	111.0	37.0	2.60	1800
108.0	18.50	1.84	110.0	41.4	2.58	1800
109.5	19.50	1.87	110.8	46.8	2.33	1800
109.0	20.00	1.84	110.5	50.3	2.34	1800
108.5	21.00	1.84	110.6	55.2	2.36	1800
109.0	22.00	1.85	110.8	60.2	2.40	1800

V_m - Motor voltage.

V_g - Generator voltage.

I_m - Total motor current.

I'_m - Field .. ..

I_g - Armature generator current.

I'_g - Field .. ..

S - Speed in r.p.m.

CALCULATED DATA.

KAPP'S OPPOSITION METHOD. (Test Two.) April 15, 1910.

S	I_m	W_p	I_g	EI	E_g	E_m
1800	9.90	1108	00.0	0000	00.00	00.00
1800	14.90	1662	7.4	986	54.26	68.65
1800	15.25	1678	11.4	1524	64.49	73.85
1800	15.50	1698	17.7	2213	72.24	78.35
1800	16.00	1744	22.5	2740	75.85	80.72
1800	16.50	1794	25.9	3151	77.84	81.84
1800	17.00	1844	31.8	3790	80.43	83.65
1800	17.75	1934	37.0	4390	81.94	84.75
1800	18.50	1994	41.4	4833	82.89	85.46
1800	19.50	2136	46.8	5441	83.59	86.00
1800	20.00	2180	50.3	5807	84.18	86.35
1800	21.00	2378	55.2	6361	84.81	86.80
1800	22.00	2398	60.2	6932	85.25	87.15

S - Speed in r.p.m.

I_g- Generator armature current.

I_m- ~~Motor~~ Line .. ..

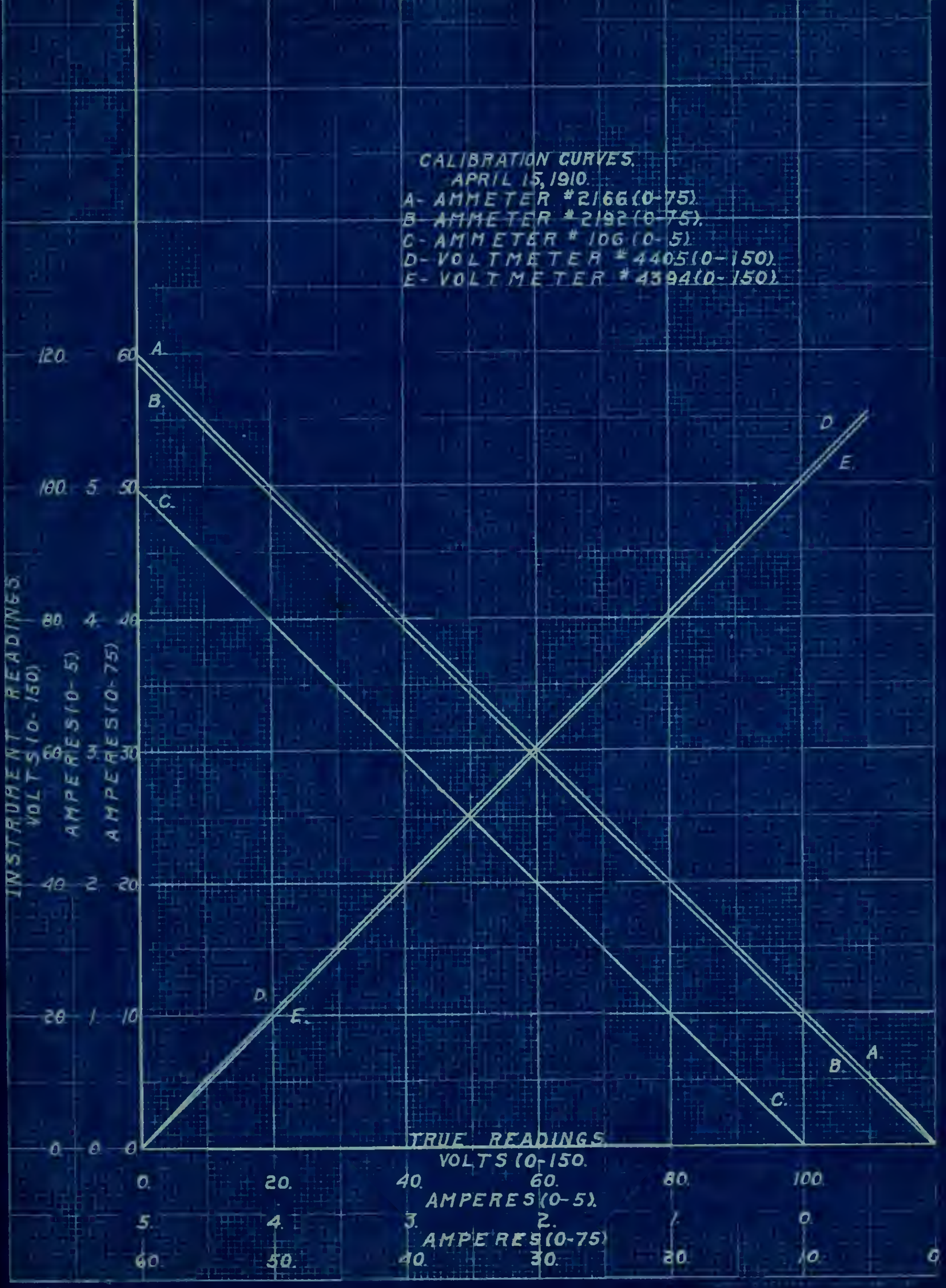
W_p- Losses in both machines.

EI- Generator output.

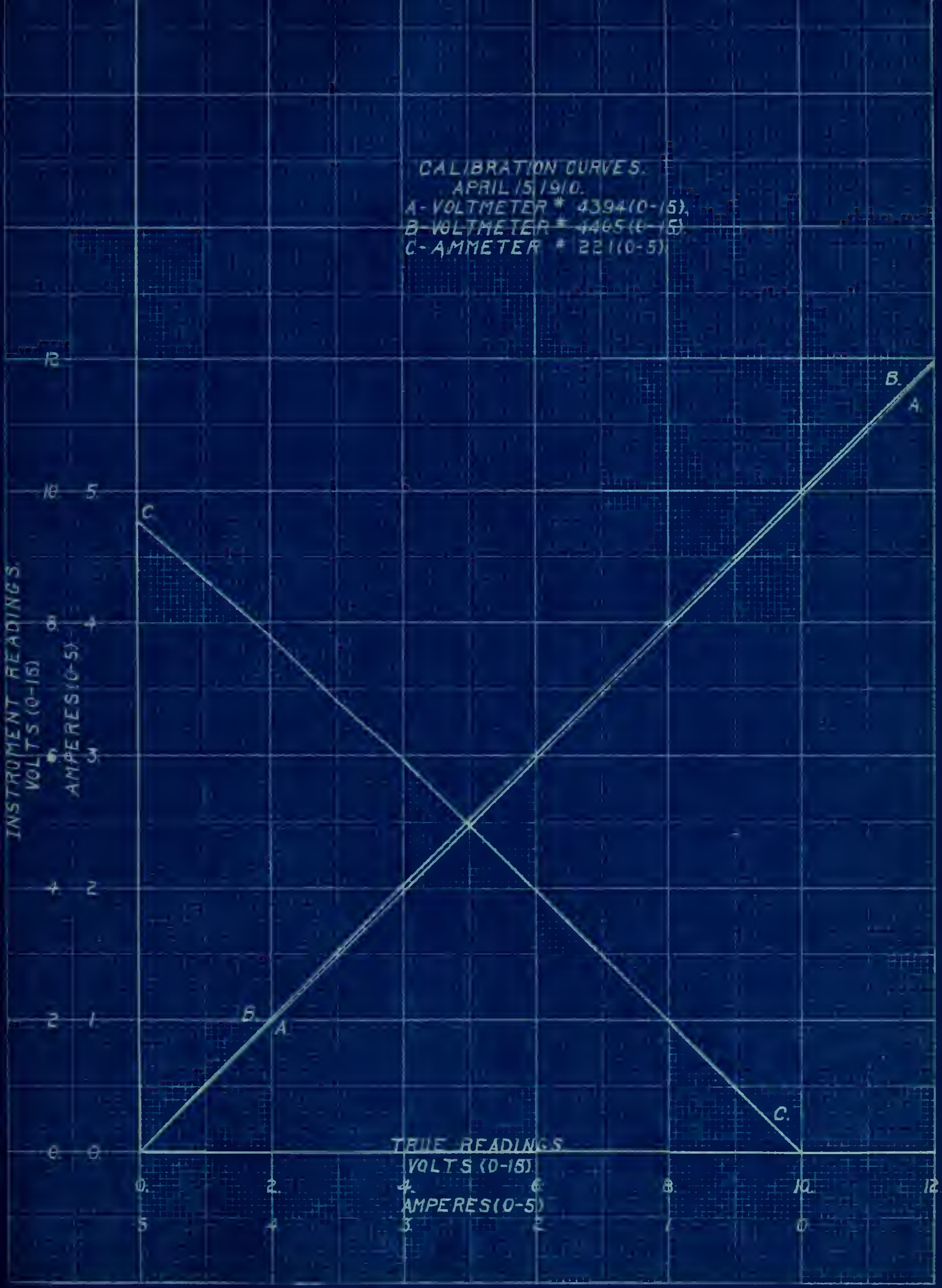
E_g- Commerical efficiency of generator.

E_m- .. .. .. motor.

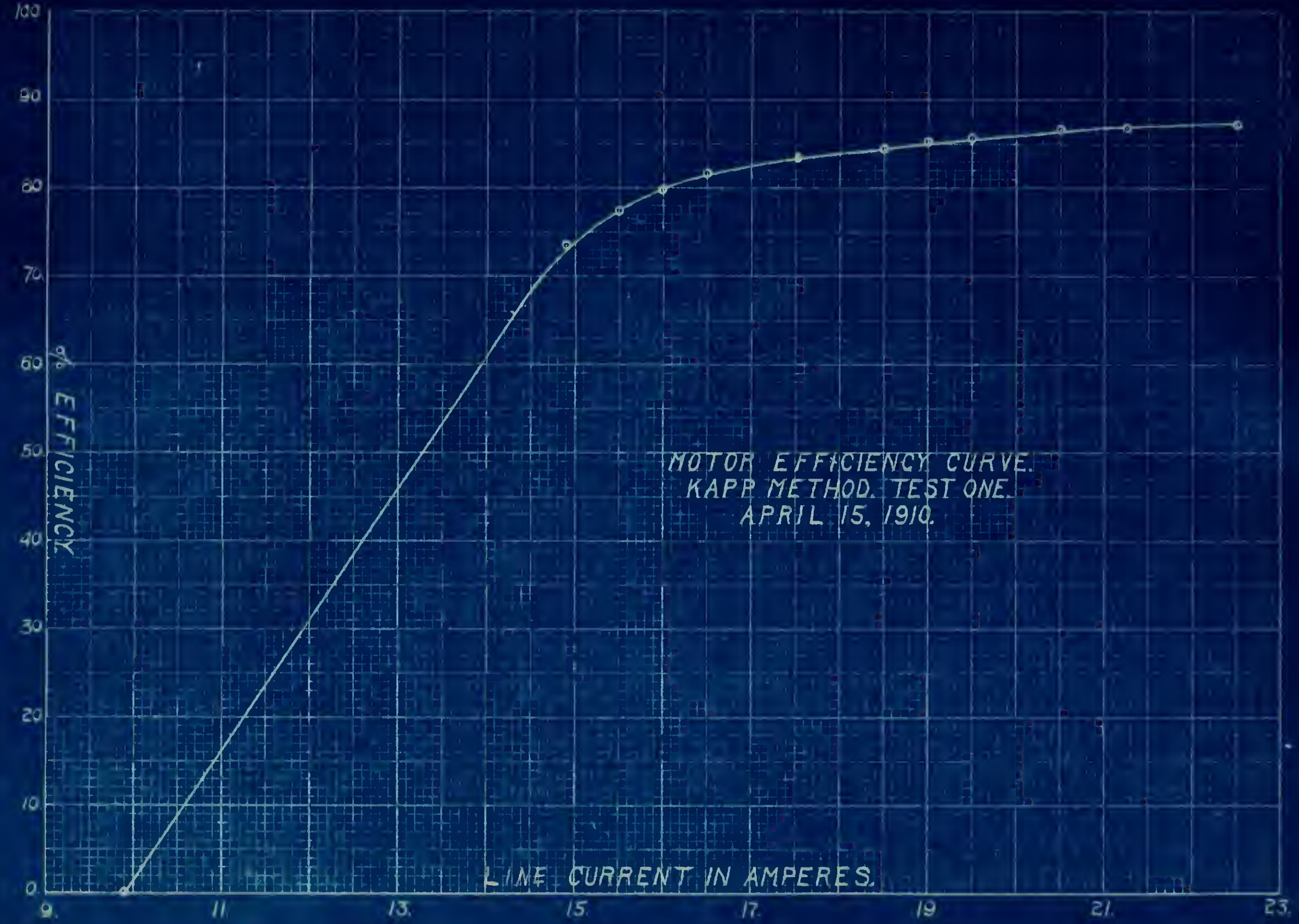
I''_m = motor current = $I_g + I_m$



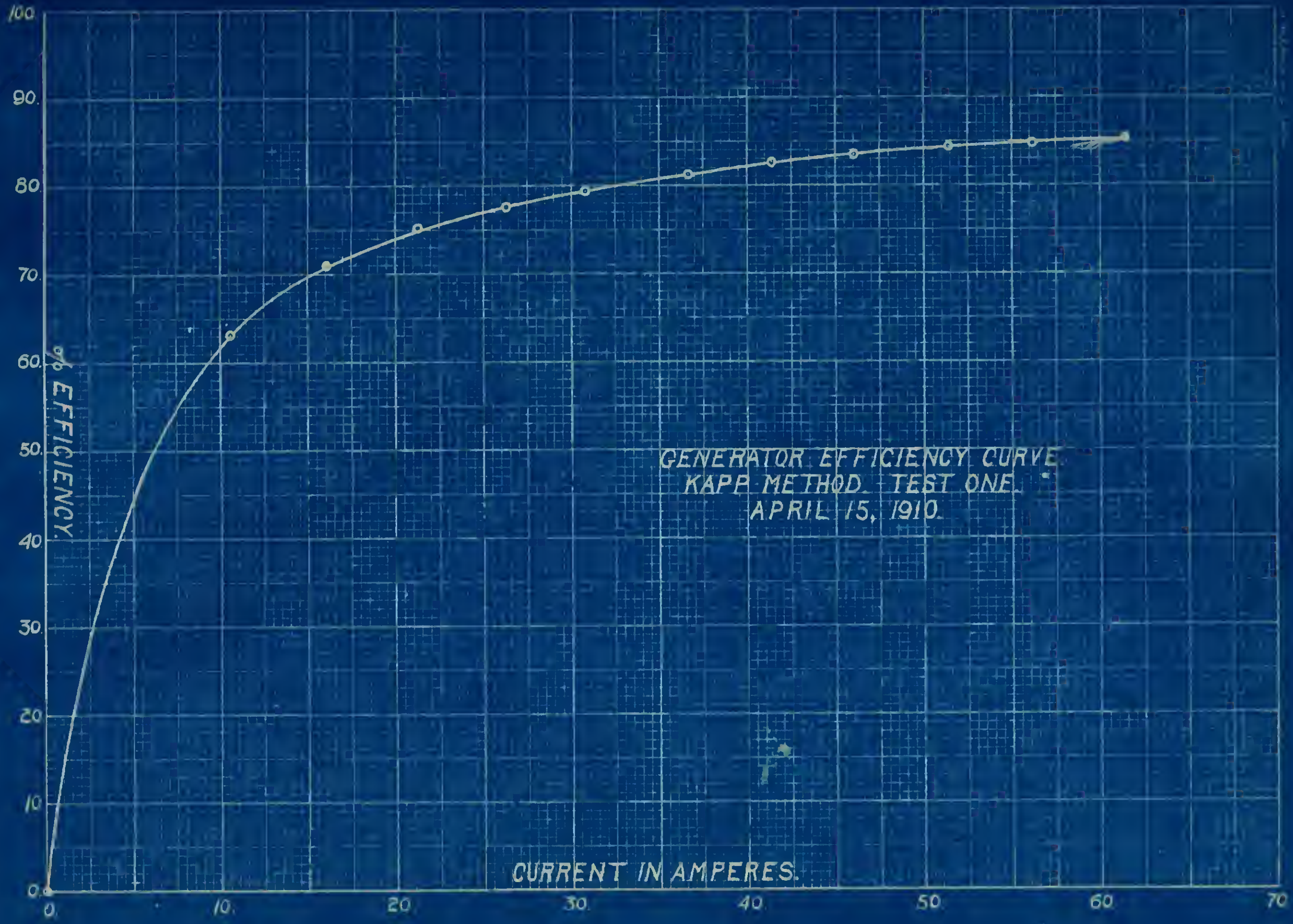
CALIBRATION CURVES.
APRIL 15, 1910.
A- AMMETER #2166 (0-75).
B- AMMETER #2192 (0-75).
C- AMMETER #106 (0-5).
D- VOLTMETER #4405 (0-150).
E- VOLTMETER #4394 (0-150).



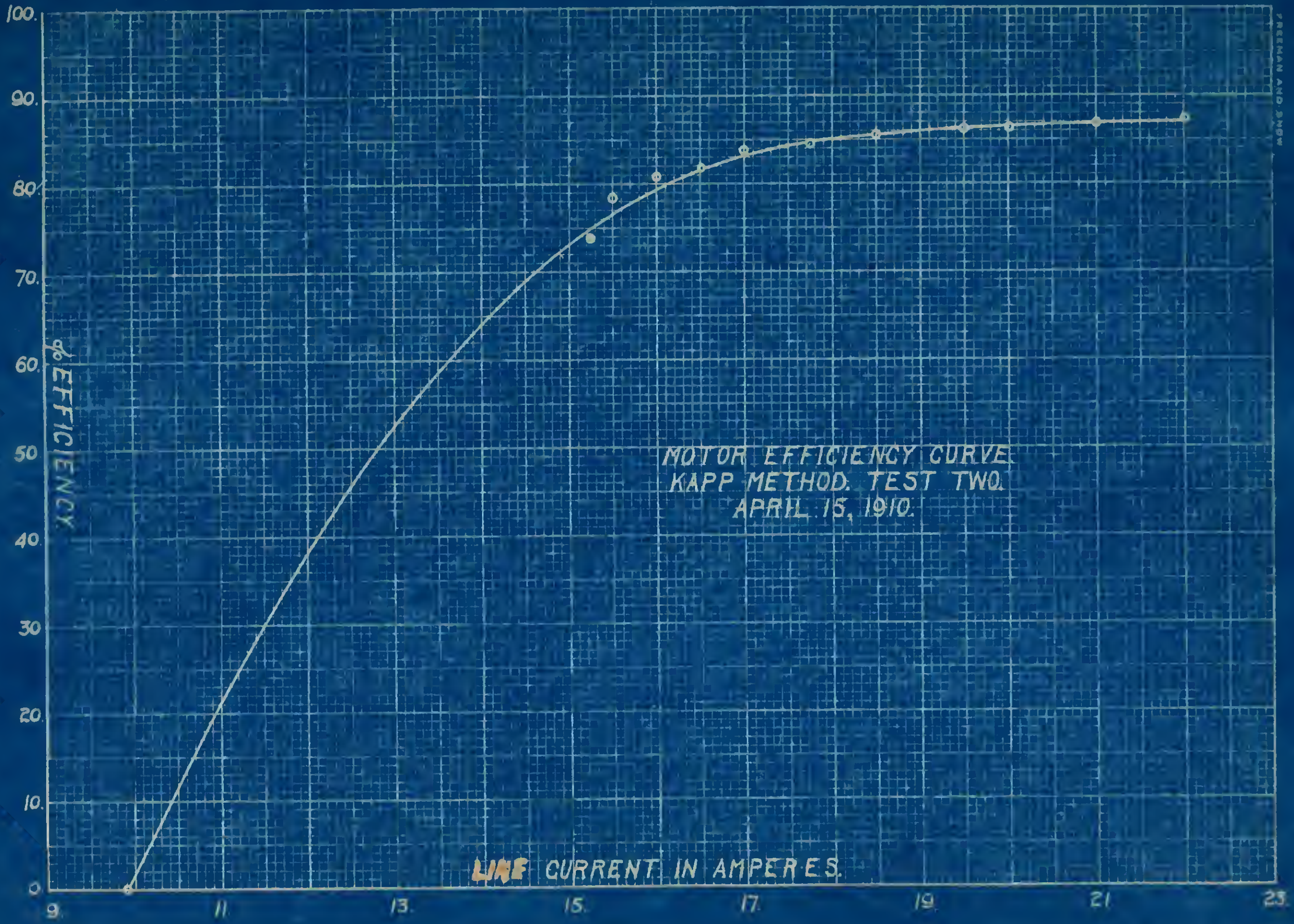
CALIBRATION CURVES.
APRIL 15, 1910.
A-VOLTMETER # 4394 (0-15).
B-VOLTMETER # 4405 (0-15).
C-AMMETER # 221 (0-5).



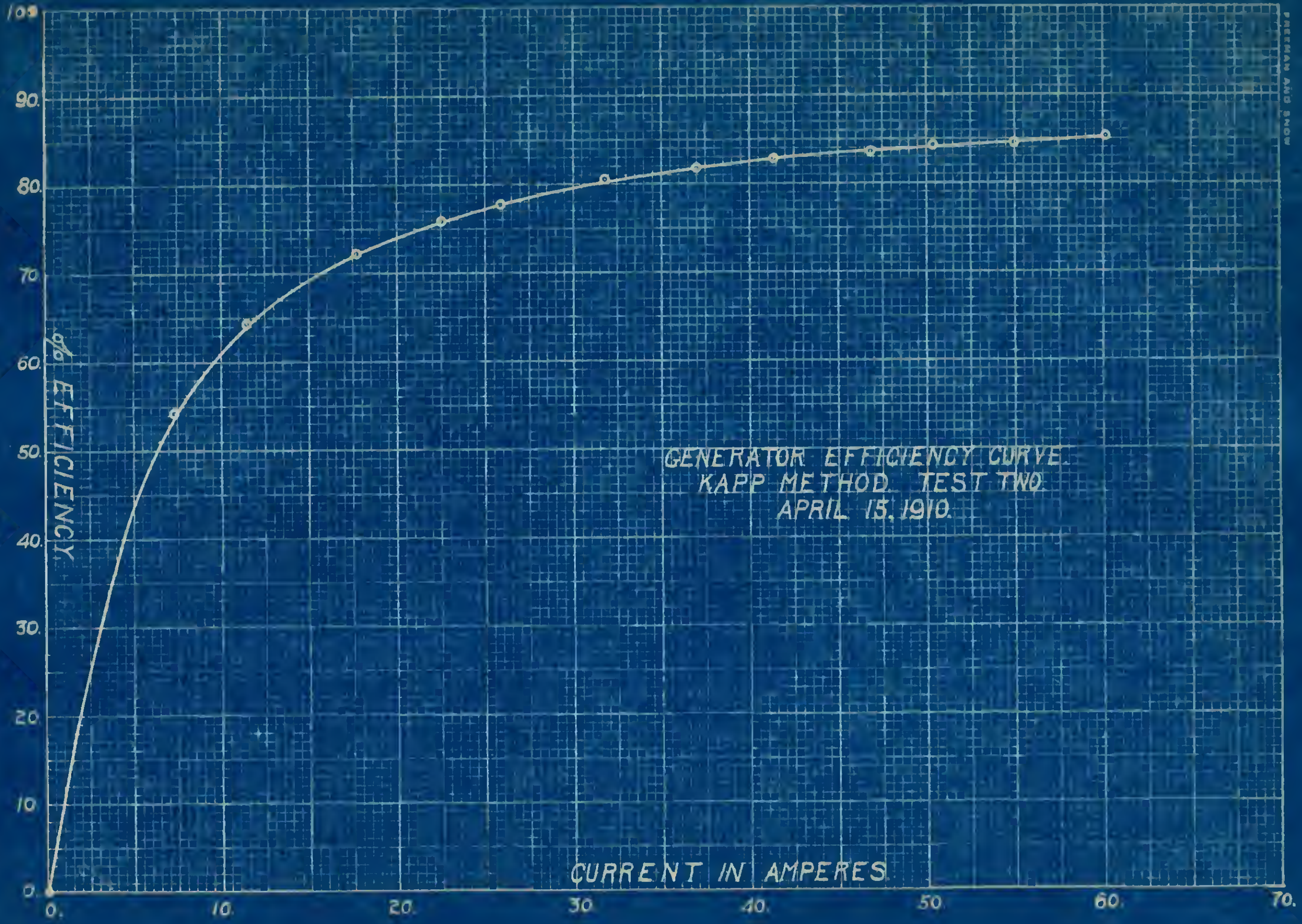
MOTOR EFFICIENCY CURVE.
KAPP METHOD. TEST ONE.
APRIL 15, 1910.



GENERATOR EFFICIENCY CURVE
KAPP METHOD. TEST ONE.
APRIL 15, 1910.



MOTOR EFFICIENCY CURVE
KAPP METHOD. TEST TWO.
APRIL 15, 1910.


GENERATOR EFFICIENCY CURVE
KAPP METHOD. TEST TWO.
APRIL 15, 1910.

PART 5.

HUTCHINSON'S OPPOSITION METHOD.

The scheme of connections for this method are as shown in the diagram on page 51. The object in this test is to obtain an opposition method which will permit the losses in the two machines being made more nearly equal than in the Hopkinson and Kapp methods. In the present method the fields were maintained equal and, consequently, the stray power was the same in the two machines. This method retains the advantage of economy of power. Here the fields received the same excitation and since the machines were mechanically connected the stray power in each may be considered equal. The armature copper loss, however, is somewhat larger in the motor than in the generator.

In this test the two machines were both electrically and mechanically connected. The set was started from the line through the starting box, the switch between the two machines being open. When the machines were up to speed, the generator field was excited, and when the voltages of the

two machines were approximately equal and opposite, the switch between the machines was closed. After this the required current was established between the two machines by suitably exciting the booster. In this method the copper loss was supplied by the booster. The field current was maintained equal in the two machines in order to have the same iron loss.

For calculating the commercial efficiency of the motor we used the following equation.

$$\text{Com. Eff.} = \frac{E_m\ I_m - \frac{1}{2}\ (2\ E_f I_f + I_g E_B + E_m\ I_x)}{E_m\ I_m}$$

For calculating the commercial efficiency of the generator we used the following equation.

$$\text{Com. Eff.} = \frac{E_g\ I_g}{E_g\ I_g + \frac{1}{2}\ (2 E_f I_f + I_g E_B + E_m\ I_x)}$$

where E_B = pressure across the terminals of booster.

E_g = pressure across the terminals of generator.

E_m = pressure across the terminals of motor.

E_f = pressure across fields of generator and motor.

I_g = current in armature of generator.

I_m = current in armature of motor.

I_x = current supplied by the mains.

I_f = current in fields of motor or generator.

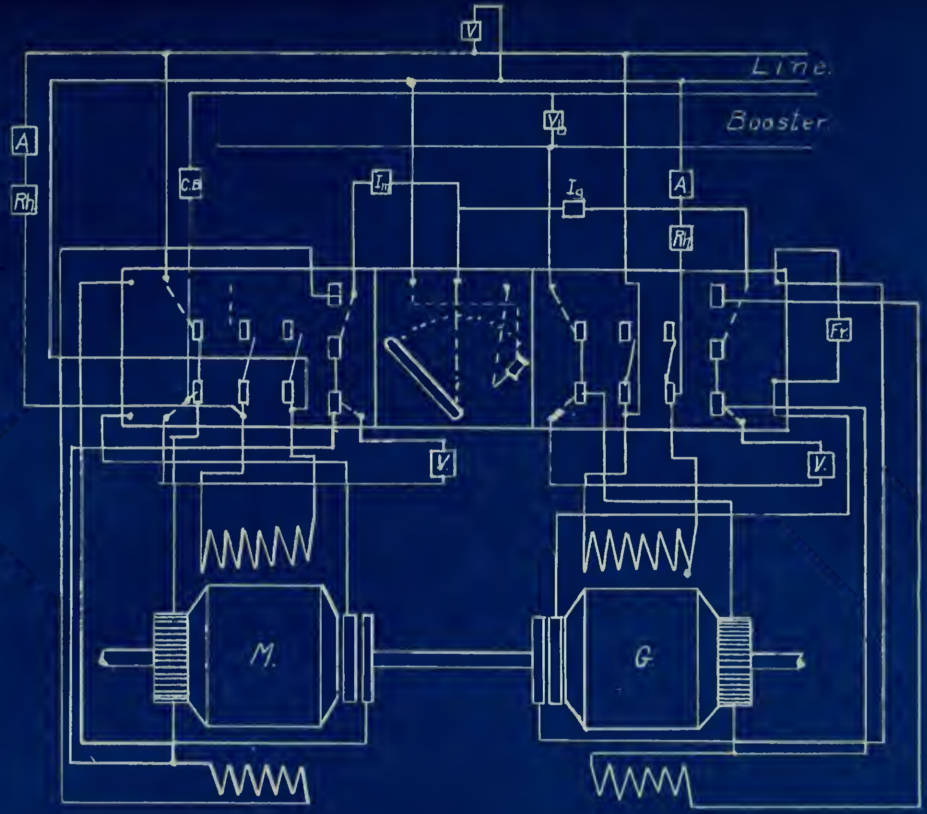
$I_m = I_g + I_x$

$I_m E_m$ = total power delivered to armature of motor.

$E_B I_g$ = copper loss.

$2 E_f I_f$ = field losses.

$(I_m - I_g) E_m = I_x E_m$ = stray power loss.



Connections for Hutchinson's Opposition Method.

EXPERIMENTAL DATA.

HUTCHINSON'S OPPOSITION METHOD. (Test One.) April 22, 1910.

E_m	E_g	E_b	E_f	I_m	I_g	I'_m	I'_g	I_x
109.6	104.5	7.13	109.6	12.9	0.0	2.11	2.16	12.9
108.0	101.3	9.51	108.0	17.7	5.0	2.09	2.14	12.7
107.6	106.2	10.32	107.6	22.9	10.0	2.07	2.12	12.9
107.0	99.3	10.94	107.0	27.7	15.0	2.05	2.09	12.7
107.0	98.6	11.55	107.0	32.7	20.0	2.05	2.10	12.7
106.6	97.6	12.14	106.6	37.6	25.0	2.04	2.08	12.6
106.4	97.6	12.81	106.4	42.5	30.0	2.04	2.08	12.5
106.2	96.7	13.20	106.2	47.5	35.2	2.04	2.08	12.3
106.4	96.3	14.86	106.4	52.5	40.0	2.04	2.08	12.5
106.2	95.7	15.00	106.2	57.2	45.0	2.04	2.08	12.2
105.8	94.9	15.90	105.8	62.5	50.0	2.04	2.08	12.5
106.0	94.7	16.05	106.0	67.6	55.6	2.04	2.08	12.0
106.0	94.5	16.40	106.0	72.5	60.5	2.04	2.08	12.0

Speed constant at 1800 R.P.M.

E_m- Pressure across terminals of motor.
E_g- .. .. generator.
E_b- .. .. booster.
E_f- .. .. fields of motor and generator.
I_m- Current in armature of motor.
I_g- .. .. generator.
I'_m- .. .. field of motor.
I'_g- .. .. generator.
I_x- .. supplied by mains.

CALCULATED DATA.

HUTCHINSON'S OPPOSITION METHOD. (Test One.) April 22, 1910.

I_m	E_mI_m	$2E_fI_f$	E_bI_g	E_mI_x	E_m
12.9	1413.8	462.5	0.0	1414.0	33.50
17.7	1911.6	451.4	47.6	1372.4	50.85
22.9	2464.0	445.5	103.2	1388.0	58.35
27.7	2963.9	438.7	164.1	1358.9	66.90
32.7	3498.9	438.7	231.0	1358.9	71.15
37.6	4008.2	434.9	305.5	1343.2	74.20
42.5	4522.0	434.1	384.3	1330.0	76.25
47.5	5044.5	433.3	464.6	1295.6	78.20
52.5	5586.0	434.1	594.4	1330.0	79.00
57.2	6074.6	433.3	675.0	1295.0	80.15
62.5	6612.5	431.7	795.0	1322.5	80.65
67.6	7165.6	432.5	892.4	1272.0	81.75
72.5	7685.0	432.5	992.0	1272.0	82.35

I_m- Current in armature of motor.

E_mI_m- Total power delivered to armature of motor.

$2E_fI_f$- Field losses.

E_bI_g- Copper loss.

E_mI_x- Stray power losses.

E_m- Commerical efficiency of the motor.

CALCULATED DATA.

HUTCHINSON'S OPPOSITION METHOD. (Test One.) April 22, 1910.

I_g	E_gI_g	$2E_fI_f$	E_bI_g	E_mI_x	E_g
0.0	0.0	463.5	0.0	1413.8	0.0
5.0	506.5	462.2	47.6	1371.6	34.45
10.0	1062.0	456.2	103.2	1388.0	52.35
15.0	1489.5	447.0	164.1	1358.9	60.35
20.0	1972.0	449.0	231.0	1358.9	65.95
25.0	2440.0	443.5	305.5	1343.2	70.00
30.0	2928.0	442.6	384.3	1330.0	73.15
35.2	3403.8	441.8	464.6	1295.6	75.60
40.0	3852.0	442.6	594.4	1330.0	76.50
45.0	4306.5	441.8	675.0	1295.6	78.15
50.0	4745.0	440.0	795.0	1322.5	78.75
55.6	5265.3	441.0	892.4	1272.0	80.25
60.5	5717.3	441.0	992.2	1272.0	81.40

I_g- Current in armature of generator.

E_gI_g- Total power delivered to armature of generator.

$2E_fI_f$- Field losses.

E_bI_g - Copper loss.

E_mI_x - Stray power losses.

E_g-Commerical efficiency of the generator.

EXPERIMENTAL DATA.

HUTCHINSON'S OPPOSITION METHOD. (Test Two.) April 22, 1910.

E_m	E_g	E_b	E_f	I_m	I_g	I'_m	I'_g	I_x
106.0	101.8	0.00	106.0	12.6	0.0	2.03	2.07	12.6
106.2	99.9	9.50	106.2	17.6	5.0	2.03	2.07	12.6
106.2	99.4	10.19	106.2	22.8	10.1	2.03	2.07	12.7
106.1	98.7	10.94	106.1	27.5	14.8	2.03	2.07	12.7
106.4	98.6	11.15	106.4	32.6	20.0	2.02	2.06	12.6
106.4	98.2	11.67	106.4	37.6	25.0	2.02	2.06	12.6
106.1	97.6	12.17	106.1	42.4	29.6	2.02	2.06	12.8
106.2	96.9	12.98	106.2	47.4	34.6	2.04	2.08	12.8
106.6	96.9	13.29	106.6	52.6	40.0	2.04	2.08	12.6
106.8	96.6	14.00	106.8	57.1	44.5	2.04	2.08	12.6
106.4	95.7	15.00	106.4	62.0	49.5	2.04	2.08	12.5
106.6	95.2	15.95	106.6	67.6	55.2	2.04	2.08	12.4
106.0	94.5	16.40	106.0	72.5	60.5	2.04	2.08	12.0

Speed constant at 1800 R.P.M.

E_m - Pressure across terminals of motor.

E_g - .. .. generator.

E_b - .. .. booster.

E_f - .. .. fields of motor and generator.

I_m - Current in armature of motor.

I_g - .. .. generator.

I'_m - .. .. field of motor.

I'_g - .. .. generator.

I_x - .. supplied by mains.

CALCULATED DATA.

HUTCHINSON'S OPPOSITION METHOD. (Test Two.) April 22, 1910.

I_m	E_mI_m	$2E_fI_f$	E_bI_g	E_mI_x	E_m
12.6	1336.0	430.2	0.0	1335.6	33.95
17.6	1869.0	431.1	47.5	1338.1	51.45
22.8	2421.0	431.1	102.9	1348.7	61.10
27.5	2918.0	431.8	161.9	1347.5	66.85
32.6	3468.0	429.9	223.0	1340.6	71.30
37.6	4000.0	429.9	281.7	1340.6	74.45
42.4	4498.6	428.6	360.2	1358.0	76.25
47.4	5033.9	433.3	449.1	1359.4	77.80
52.6	5607.2	434.9	531.6	1343.2	79.50
57.11	6098.3	435.9	623.0	1345.7	80.30
62.0	6596.8	434.1	742.5	1330.0	81.00
67.6	7206.2	434.9	877.4	1321.8	81.25
72.5	7685.5	432.5	992.6	1272.0	82.35

I_m - Current in armature of motor.

E_mI_m - Total power delivered to the armature of motor.

$2E_fI_f$ - Field losses.

E_bI_g - Copper loss.

E_mI_x - Stray power losses.

E_m - Commerical efficiency of the motor.

CALCULATED DATA.

HUTCHINSON'S OPPOSITION METHOD. (Test Two.) April 22, 1910.

I_g	E_gI_g	$2E_fI_f$	E_bI_g	E_mI_x	E_g
0.0	0.0	438.9	0.0	1335.6	0.0
5.01	499.5	439.7	47.5	1338.1	34.15
10.1	1003.9	439.7	102.9	1348.7	50.25
14.8	1460.8	439.3	161.9	1347.5	60.10
20.0	1972.0	438.4	223.0	1340.6	66.40
25.0	2455.0	438.4	281.7	1340.6	70.45
29.6	2889.0	437.1	360.2	1358.0	72.85
34.6	3352.7	441.8	449.1	1359.4	74.95
40.0	3876.0	443.5	531.6	1343.2	77.00
44.5	4298.9	444.1	623.0	1345.7	78.00
49.5	4737.2	442.6	742.5	1330.0	78.85
55.2	5255.0	443.5	877.4	1321.8	80.00
60.5	5717.3	441.0	992.2	1272.0	81.40

I_g - Current in armature of generator.

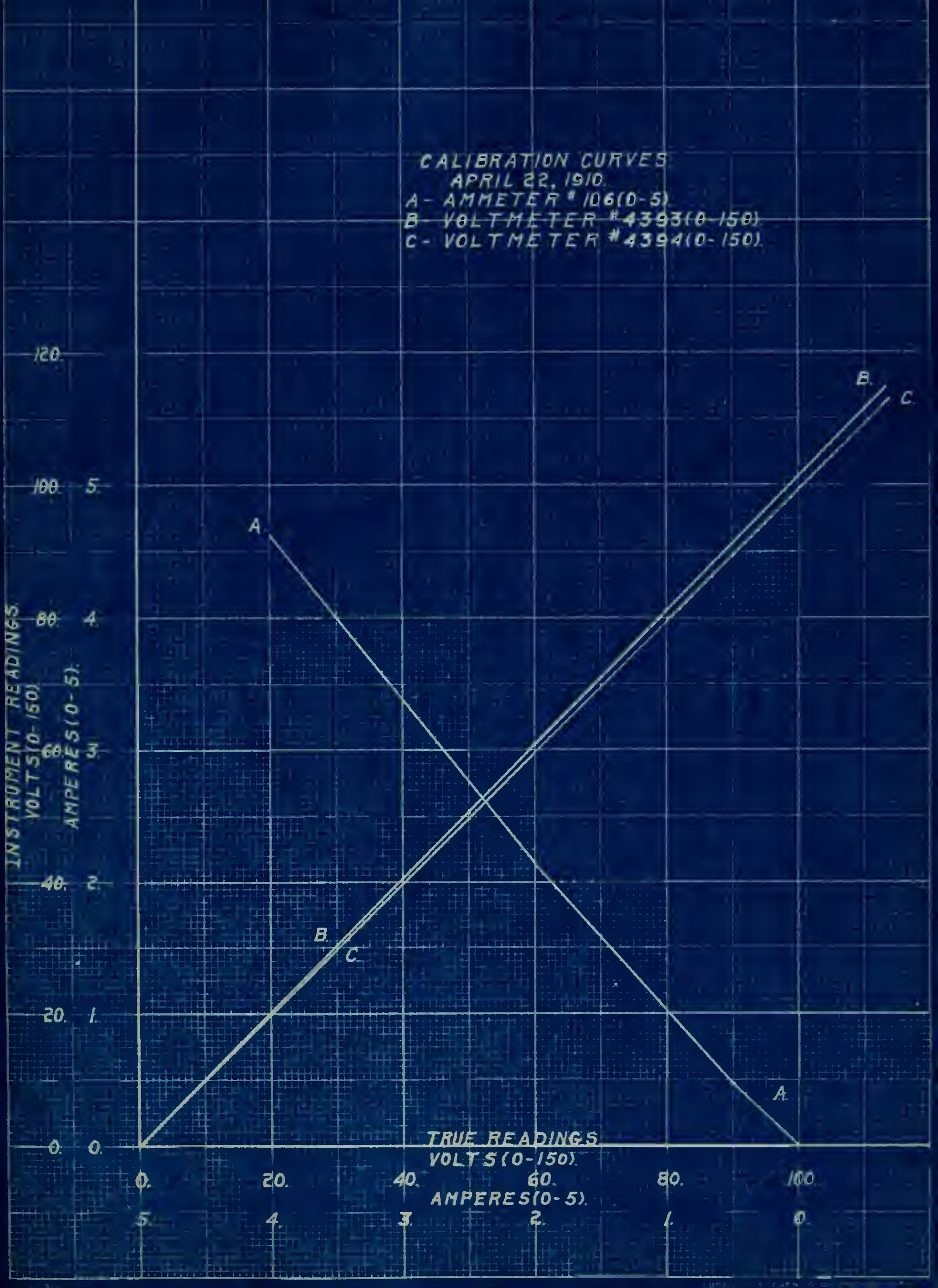
E_gI_g - Total power delivered to armature of generator.

$2E_fI_f$ - Field losses.

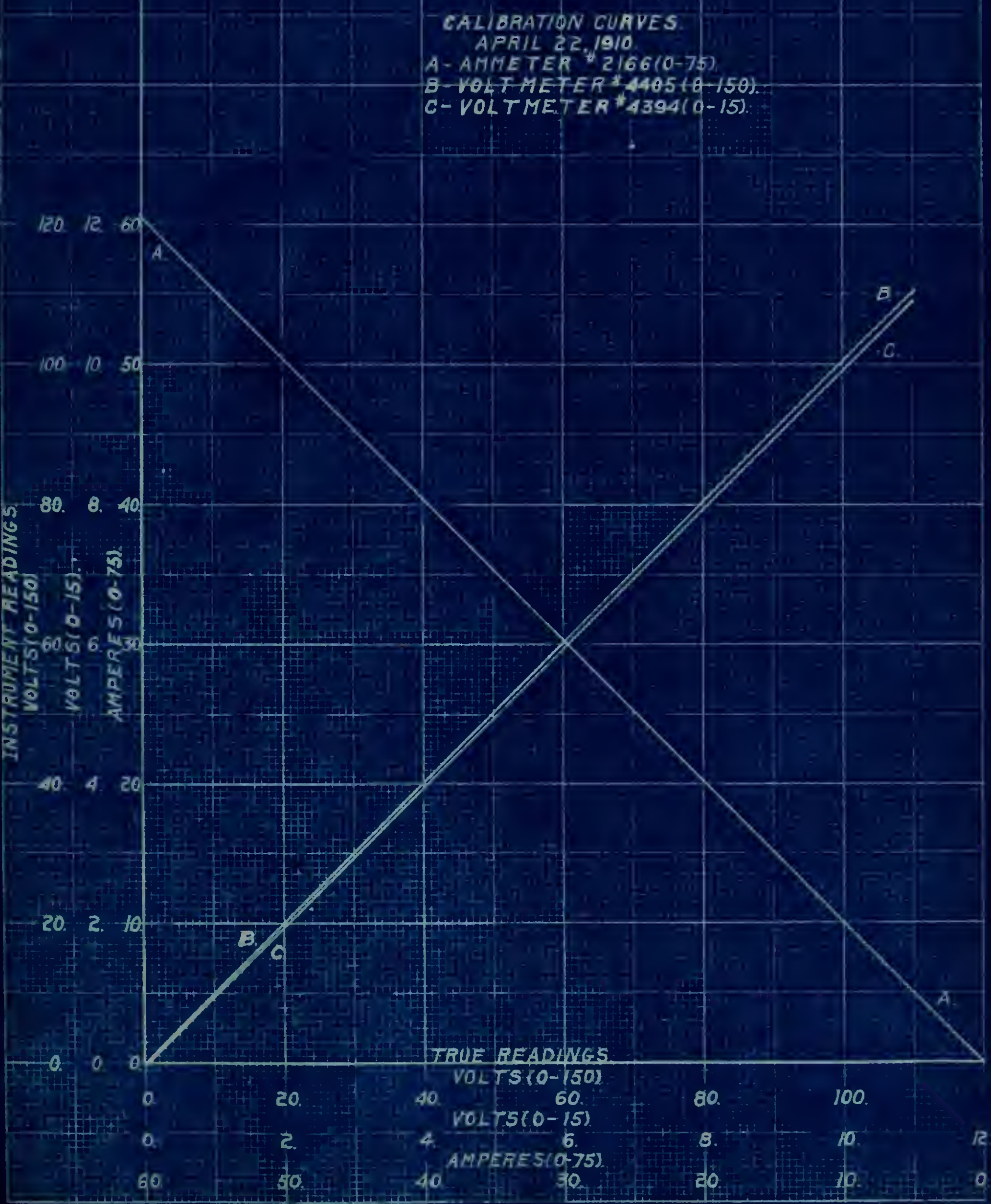
E_bI_g - Copper loss.

E_mI_x - Stray power losses.

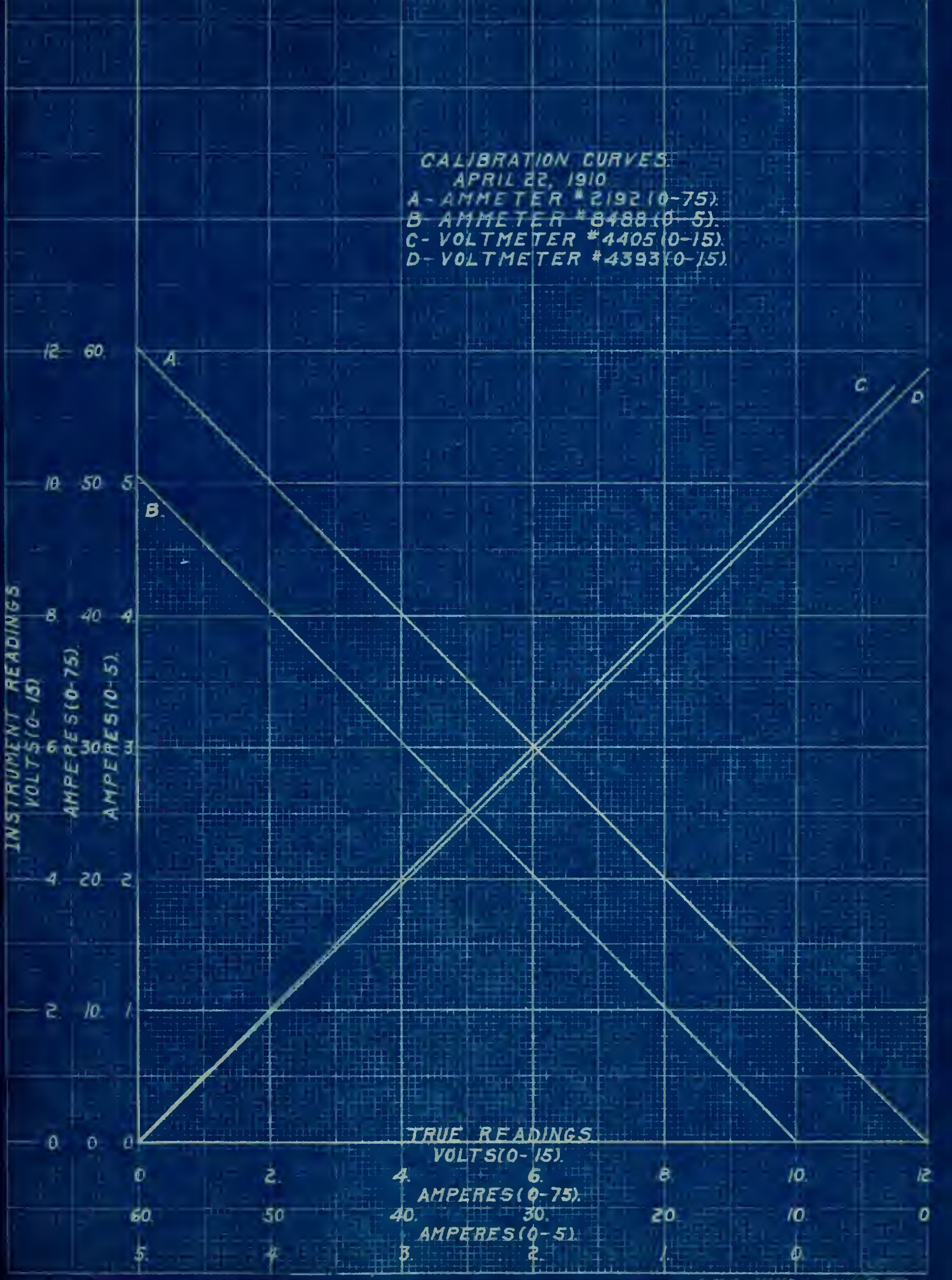
E_g - Commerical efficiency of the generator.



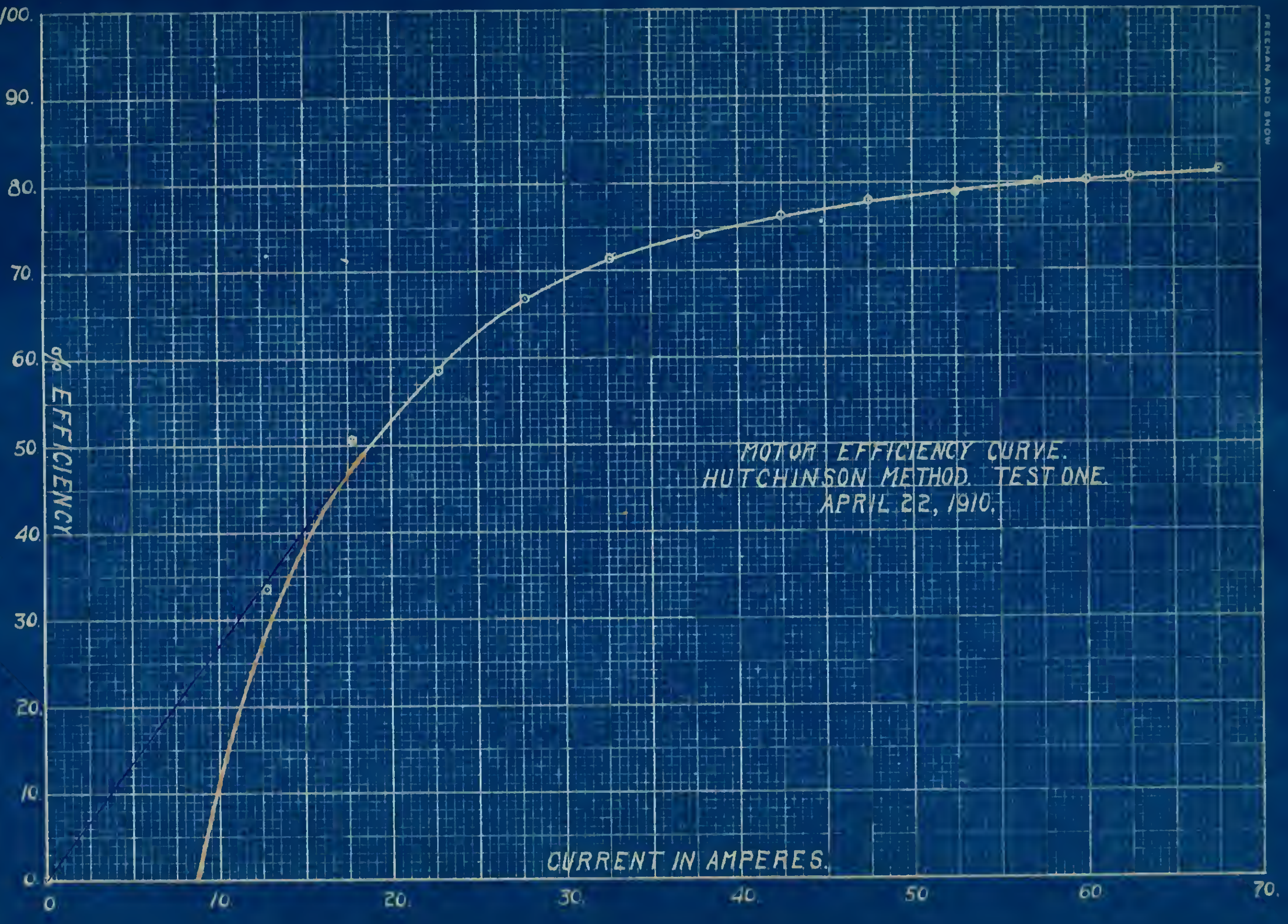
CALIBRATION CURVES.
APRIL 22, 1910.
A - AMMETER # 106(0-5).
B - VOLTMETER # 4393(0-150).
C - VOLTMETER # 4394(0-150).



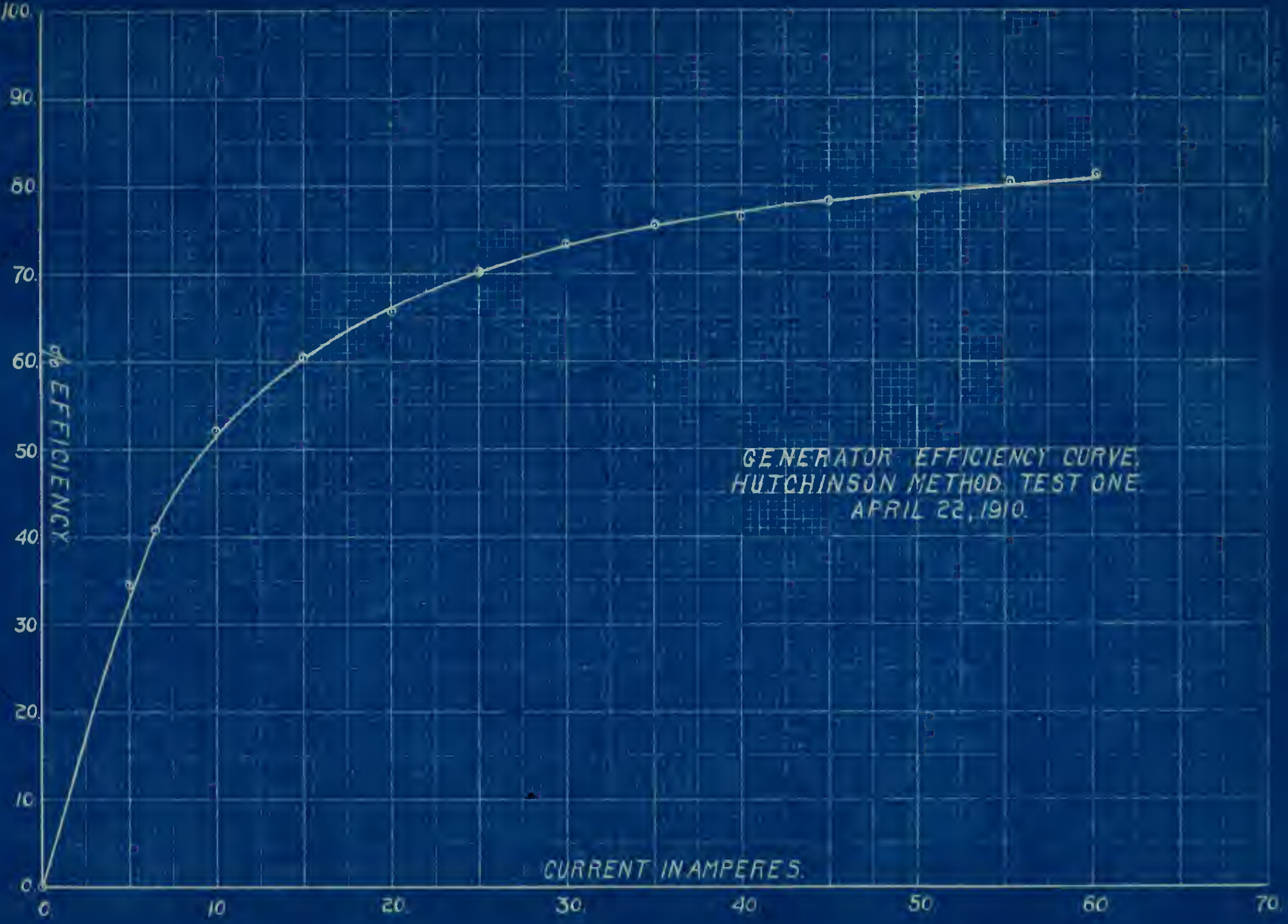
CALIBRATION CURVES.
APRIL 22, 1910.
A - AMMETER # 2166 (0-75).
B - VOLTMETER # 4405 (0-150).
C - VOLTMETER # 4394 (0-15).



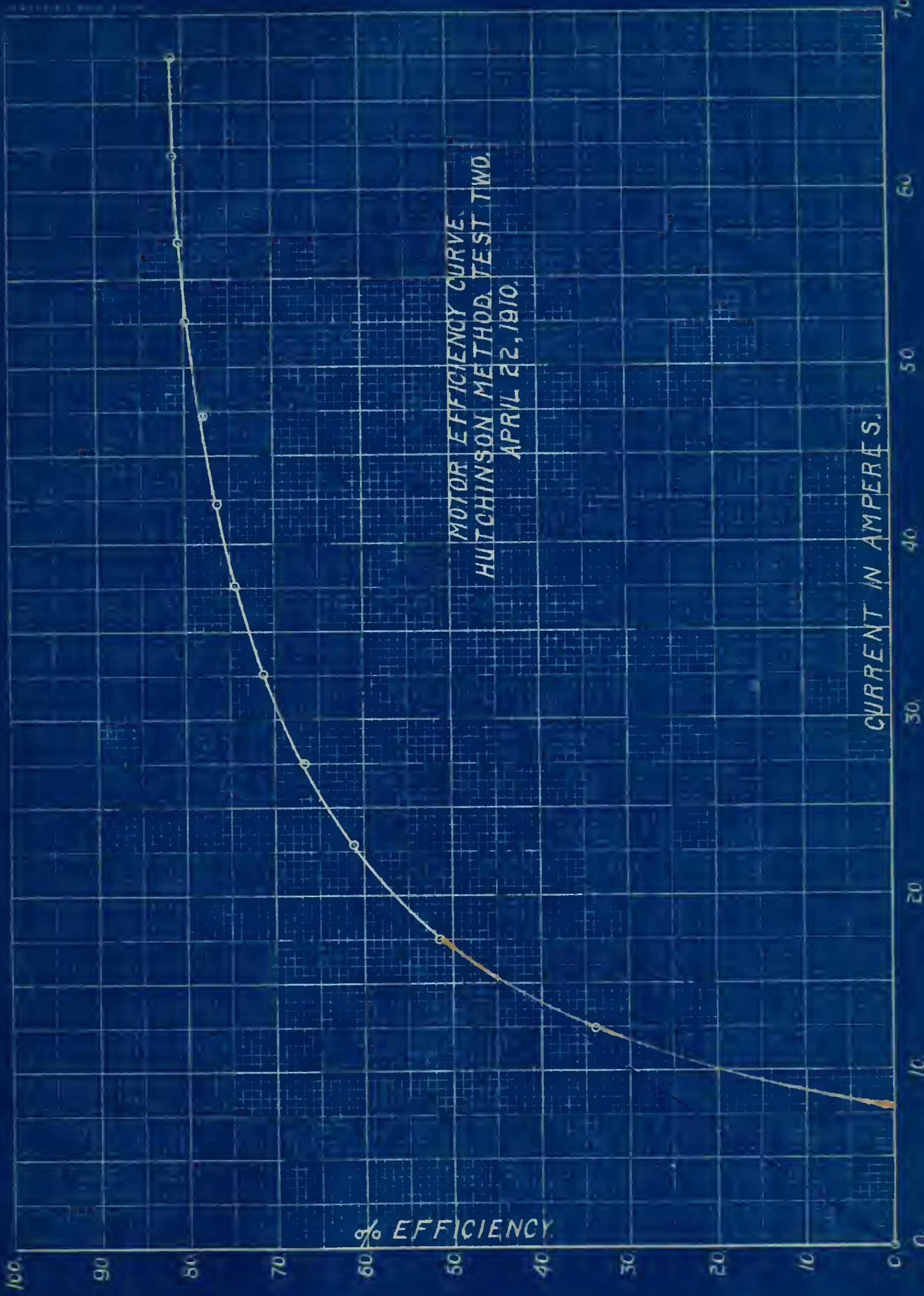
CALIBRATION CURVES
APRIL 22, 1910
A- AMMETER #2192 (0-75).
B- AMMETER #8488 (0-5).
C- VOLTMETER #4405 (0-15).
D- VOLTMETER #4393 (0-15).



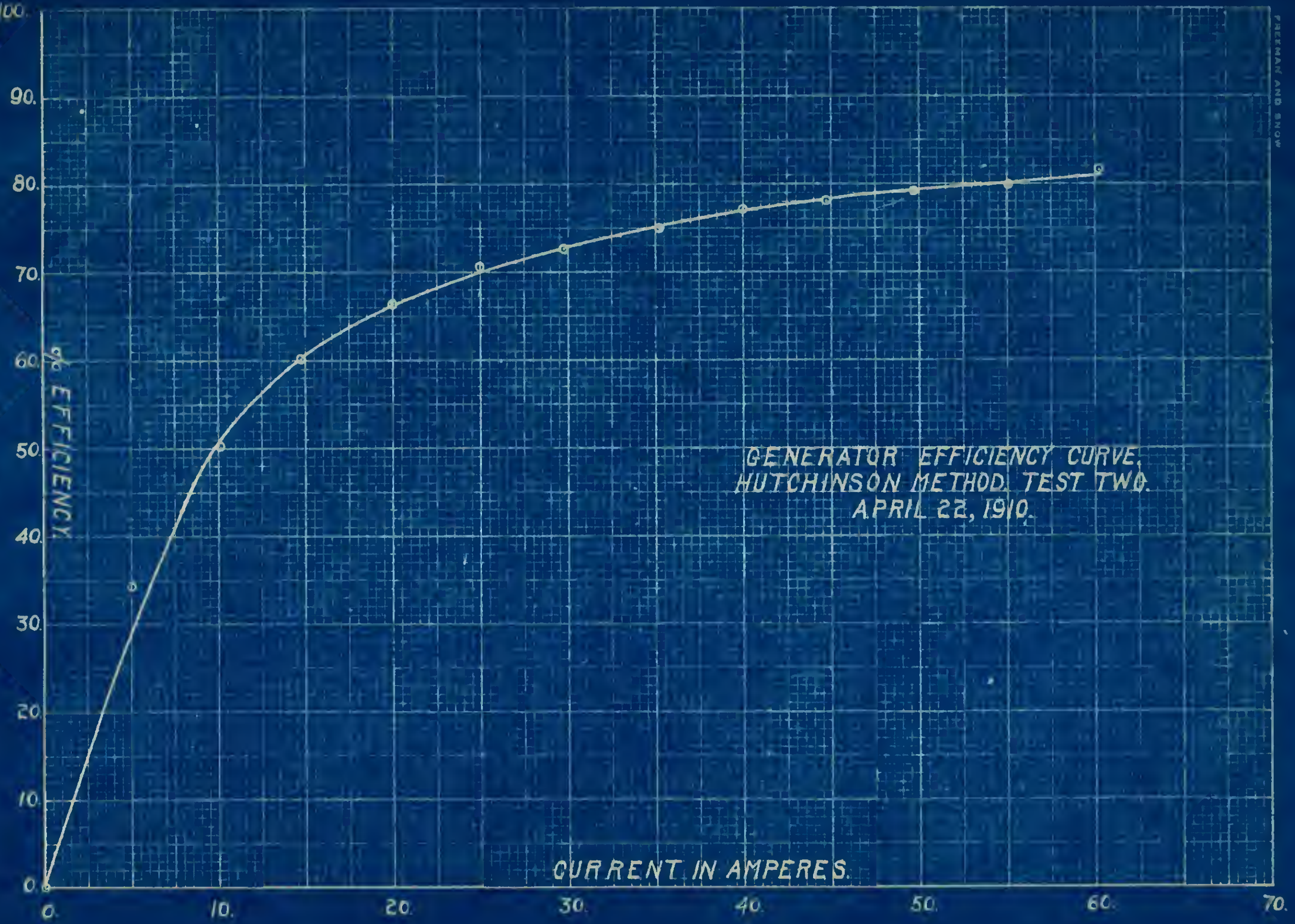
MOTOR EFFICIENCY CURVE.
HUTCHINSON METHOD. TEST ONE.
APRIL 22, 1910.



GENERATOR EFFICIENCY CURVE.
HUTCHINSON METHOD. TEST ONE.
APRIL 22, 1910.



MOTOR EFFICIENCY CURVE.
HUTCHINSON METHOD. TEST TWO.
APRIL 22, 1910.



GENERATOR EFFICIENCY CURVE.
HUTCHINSON METHOD. TEST TWO.
APRIL 22, 1910.

PART - 6.

BLONDEL OPPOSITION METHOD.

The scheme of connections for this method are as shown in the diagram on page 67. In this method the two machines under test were mechanically and electrically connected while a third machine was mechanically connected to the set. The set was started and brought up to speed by the auxiliary motor with the switch between the two electrically connected machines open. The fields of both machines were then excited to the required value, and when the voltmeter gave the same reading on each machine, the switch between the two was closed. Very little current flowed between the two machines, the armature currents being in opposition. By exciting the booster so as to add its voltage to that of the generator, any desired current could be made to circulate between the two machines. By regulating the field rheostats of the two machines, the speed of the auxiliary motor, and the booster voltage, any desired conditions of current, voltage, and speed of the set under test could be established.

The power taken from the booster supplied the copper losses in the armature. The auxiliary motor supplied the stray power losses of the two machines.

For calculating the commercial efficiency of the motor we used the following equation.

$$\text{Com.Eff.} = \frac{IE_1 - P_a - P_s}{IE_1 + P_f}$$

For calculating the commercial efficiency of the generator we used the following equation.

$$\text{Com. Eff.} = \frac{IE_2 - P_f}{IE_2 + P_a + P_s}$$

Where IE_1 = power delivered to the motor terminals

IE_2 = power delivered by the generator armature.

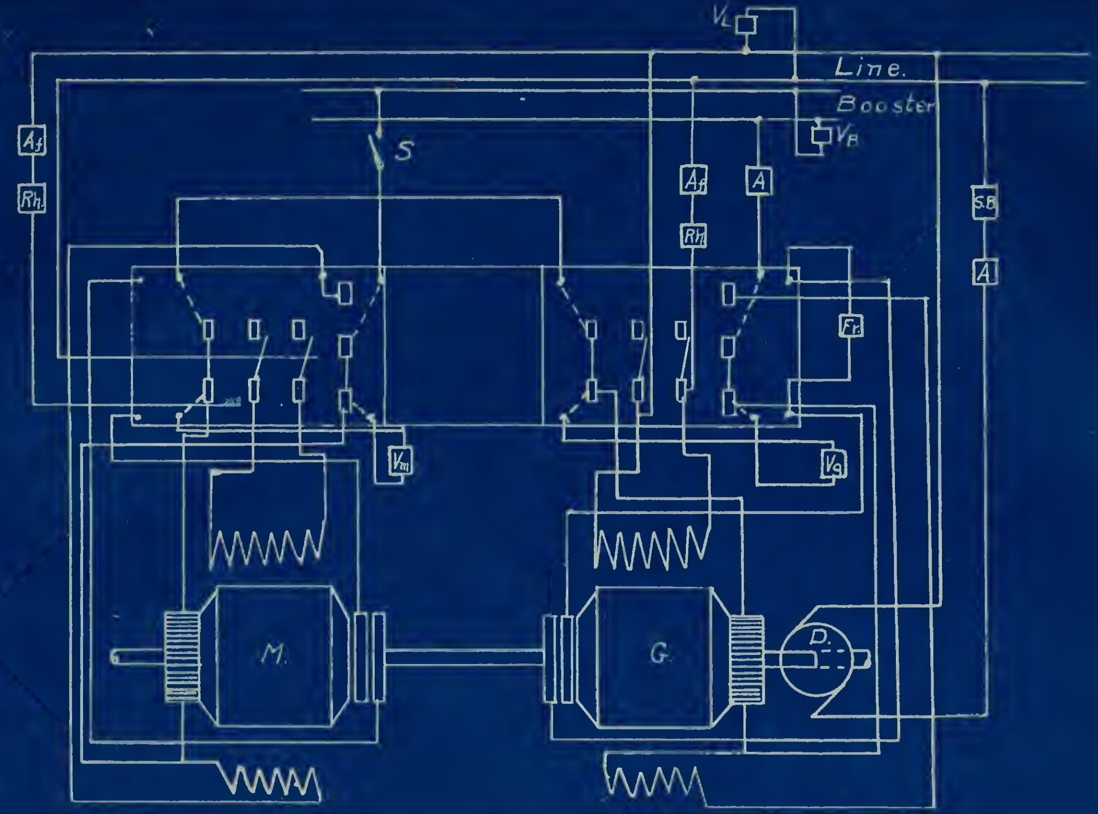
P_a = I^2R loss in armature.

P_f = I^2R loss in field.

P_s = stray power loss in either machine.

P_D = power delivered by auxiliary motor.

$$P_s = \frac{P_D}{2}.$$



Connections for Blondel's Opposition Method

EXPERIMENTAL AND CALCULATED DATA/

BLONDEL OPPOSITION METHOD. (Test One.) April 29, 1910.

I'	E	I	E_b	EI	P_s	P_a	P_f	E_m
2.18	109.6	0	.00	000	721.8	0.0	224.8	0.0
2.18	106.6	5	.88	533	721.8	2.9	224.8	----
2.18	106.2	10.2	1.73	1083	821.8	12.1	224.8	26.82
2.18	106.0	15.4	2.42	1632	726.8	27.6	224.8	42.35
2.18	105.6	20.6	3.00	2175	735.9	49.1	224.8	58.00
2.17	105.2	25.7	3.48	2706	741.5	76.6	222.7	64.55
2.17	105.1	30.7	4.07	3227	750.9	109.3	222.7	68.75
2.17	104.7	35.6	4.52	3727	764.8	146.9	222.7	71.35
2.17	105.0	40.9	4.95	4262	778.2	194.0	222.7	73.30
2.17	104.1	45.9	5.21	4778	797.3	244.3	222.7	74.65
2.17	103.3	50.8	5.85	5248	797.3	299.3	222.7	76.00
2.17	103.1	55.9	6.35	5763	811.5	362.3	220.9	76.85
2.17	103.1	59.8	6.80	6165	823.2	414.8	220.9	77.15

107.2 - Motor field voltage.

I'- .. .. current.

E - .. armature voltage.

I - .. .. current.

E_b- Booster voltage.

EI- Motor input.

P_s- Stray power loss.

P_a- Copper loss in armature.

P_f- .. .. .. field.

E_m- Commerical efficiency of the motor.

EXPERIMENTAL AND CALCULATED DATA.

BLONDEL OPPOSITION METHOD. (Test One.) April 29, 1910.

I'	E	I	E_b	EI	P_s	P_a	P_f	E_g
2.05	105.9	0	.00	000	721.8	0.0	199.6	0.0
2.05	106.9	5	.88	535	721.8	2.8	199.6	26.61
2.05	105.7	10.2	1.73	1078	721.8	11.7	199.6	48.45
2.05	106.0	15.4	2.42	1632	726.8	26.8	199.6	60.00
2.05	105.3	20.6	3.00	2169	735.9	47.9	199.6	70.15
2.04	105.3	25.7	3.48	2706	741.5	74.6	197.6	71.25
2.04	108.5	30.7	4.07	3331	750.9	106.5	197.6	74.80
2.04	108.5	35.6	4.52	3863	764.8	143.2	197.6	76.85
2.04	108.5	40.9	4.95	4438	778.2	189.1	197.6	78.45
2.04	108.5	45.9	5.21	4980	797.3	238.1	197.6	79.55
2.04	108.5	50.8	5.85	5512	797.3	291.7	197.6	80.46
2.04	108.5	55.9	6.35	6065	811.5	353.1	197.6	81.00
2.04	108.5	59.8	6.80	6488	823.2	408.0	197.6	81.60

107.2 - Generator field voltage.

I' --- .. .. current.

E - .. armature voltage.

I - .. .. current.

E_b - Booster voltage.

EI - Generator output.

P_s - Stray power loss in generator.

P_a - Copper loss in armature.

P_f - .. .. .. field.

E_g - Commerical efficiency of generator.

EXPERIMENTAL AND CALCULATED DATA.

BLONDEL OPPOSITION METHOD. (Test Two.) April 29, 1910.

I'	E	I	E_b	EI	P_s	P_a	P_f	E_m
2.16	108.5	0	0	0000	69099	0	220.9	0.0
2.16	106.2	5	1.55	531	697.8	2.9	220.9	----
2.16	106.0	10.2	1.60	1081	721.8	12.1	220.9	26.70
2.15	105.1	15.4	2.55	1619	732.8	27.5	218.7	46.65
2.16	105.1	20.6	3.10	2165	735.9	49.1	220.9	55.55
2.16	105.9	25.7	3.50	2722	750.9	76.6	220.9	64.35
2.15	105.3	30.7	4.00	3233	764.8	109.3	218.7	68.35
2.15	104.6	35.6	4.64	3724	782.0	146.9	218.7	70.90
2.16	104.4	40.9	4.96	4220	793.5	194.0	220.9	72.85
2.16	104.1	45.9	5.55	4778	793.5	244.3	220.9	74.95
2.16	103.6	50.8	6.05	5263	811.5	299.3	220.9	75.85
2.16	103.1	55.9	6.35	5763	814.1	362.3	220.9	76:50
2.17	103.1	59.8	6.80	6165	823.2	414.8	220.9	77.15

107.2 - Motor field voltage.

I'- .. .. current.

E - .. armature voltage.

I - .. .. current.

E_b- Booster voltage.

EI- Motor input.

P_s- Stray power loss.

P_a- Copper loss in armature.

P_f- .. .. .. field.

E_m- Commerical efficiency of the motor.

EXPERIMENTAL AND CALCULATED DATA.

BLONDEL OPPOSITION METHOD. (Test Two.) April 29, 1910.

I'	E	I	E_b	EI	P_s	P_a	P_f	E_g
2.03	103.5	0	.00	000	692.8	0.0	195.7	0.0
2.02	105.3	5	1.55	527	697.8	2.8	193.8	26.25
2.02	104.5	10.2	1.60	1066	721.8	11.8	193.8	47.85
2.02	105.0	15.4	2.55	1617	732.8	26.8	193.8	60.10
2.03	105.3	20.6	3.10	2167	735.9	47.9	195.7	66.80
2.03	106.6	25.7	3.50	2737	750.9	74.6	195.7	71.25
2.02	106.9	30.7	4.00	3282	764.8	106.5	193.8	74.25
2.02	107.6	35.6	4.64	3831	782.0	143.8	193.8	76.50
2.03	107.9	40.9	4.96	4413	793.5	189.1	195.7	78.20
2.03	108.5	45.9	5.55	4980	793.5	238.1	195.7	79.60
2.03	108.5	50.8	6.05	5512	811.5	291.7	195.7	80.35
2.03	108.5	55.9	6.35	6065	814.1	353.1	195.7	81.25

107.2 - Generator field voltage.

I' - .. .. current.

E - .. armature voltage.

I - .. .. current.

E_b - Booster voltage.

EI - Generator output.

P_s - Stray power loss in generator.

P_a - Copper loss in armature.

P_f - .. .. .. field.

E_g - Commerical efficiency of generator.

BLONDEL OPPOSITION METHOD. (Test One.) April 29, 1910.

Efficiency of the Northern Motor.

I	E	EI	P	E'
18.0	107.2	1930	485.4	74.8
18.0	107.2	1930	485.4	74.8
18.0	107.2	1930	485.4	74.8
18.1	107.2	1938	486.1	75.0
18.3	107.2	1960	487.7	75.1
18.4	107.2	1972	488.5	75.2
18.6	107.2	1992	489.9	75.4
18.9	107.2	2026	492.3	75.5
19.1	107.2	2048	493.9	76.0
19.5	107.2	2090	497.0	76.3
19.5	107.2	2090	497.0	76.3
19.7	107.2	2119	498.7	76.6
20.0	107.2	2144	501.2	76.8

I - Armature current.

E - Motor voltage.

EI - Motor input.

P - Losses.

E'- Motor efficiency.

BLONDEL OPPOSITION METHOD. (Test Two.) April 29, 1910.

Efficiency of the Northern Motor.

I	E	EI	P	E'
17.4	107.2	1865	481.0	74.3
17.5	107.2	1876	481.7	74.4
18.0	107.2	1930	485.4	74.8
18.2	107.2	1949	486.8	75.1
18.3	107.2	1960	487.7	75.1
18.6	107.2	1992	489.9	75.4
18.9	107.2	2026	492.3	75.5
19.2	107.2	2058	494.8	76.0
19.4	107.2	2080	496.3	76.3
19.4	107.2	2080	496.3	76.3
19.7	107.2	2119	498.7	76.6
19.8	107.2	2123	499.5	76.7
20.0	107.2	2144	501.2	76.8

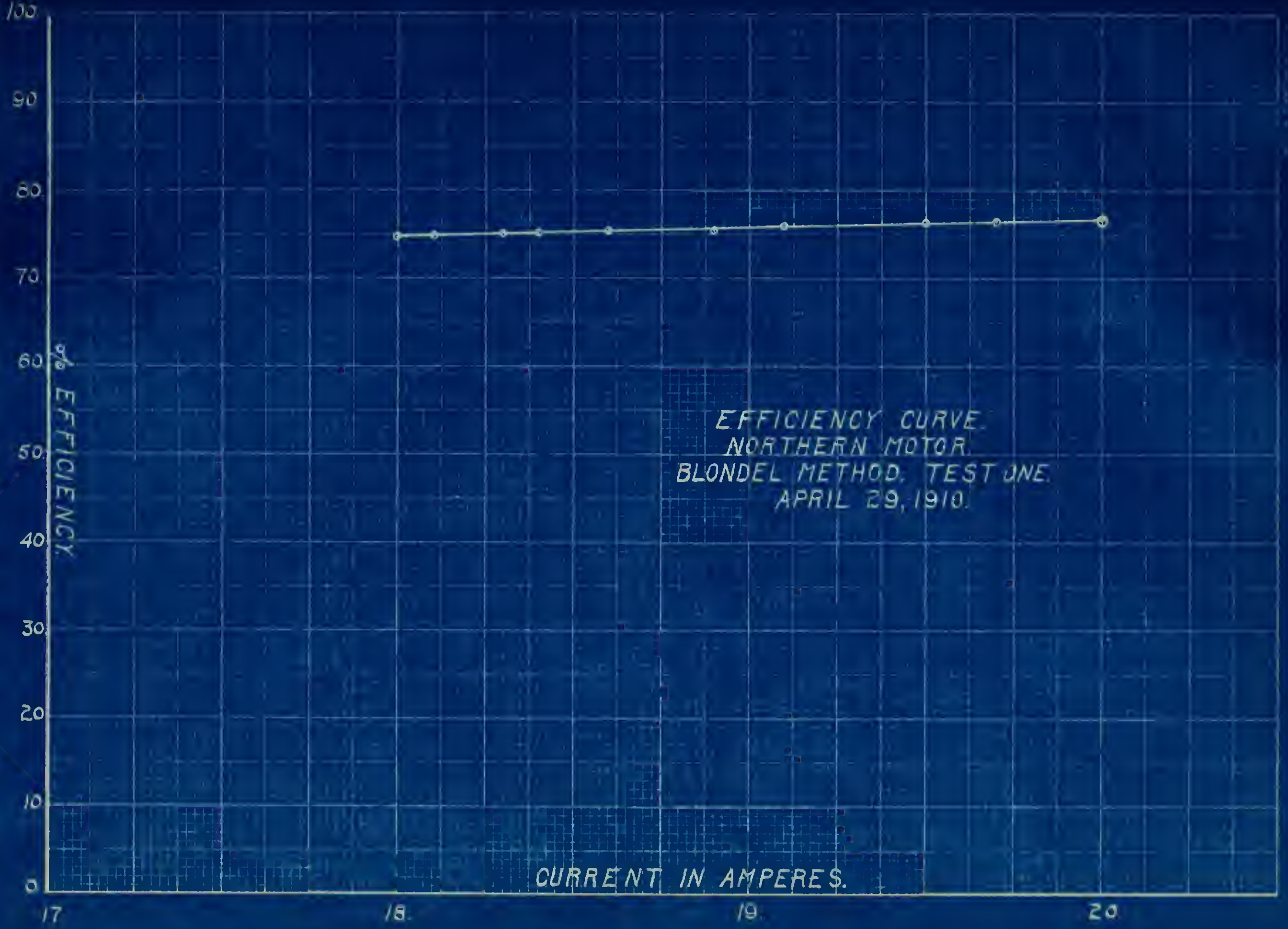
I - Armature current.

E - Motor voltage.

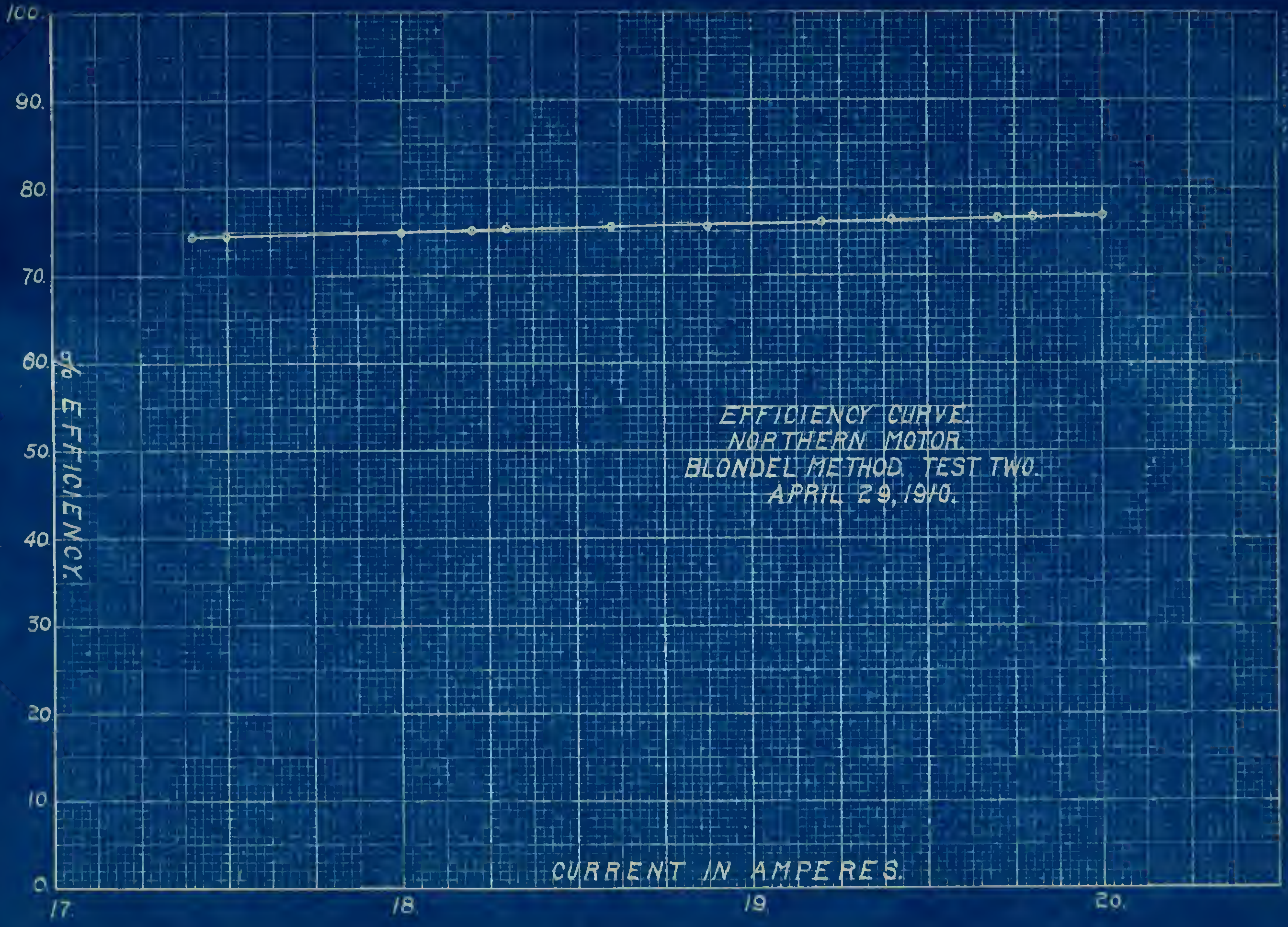
EI - Motor input.

P - losses.

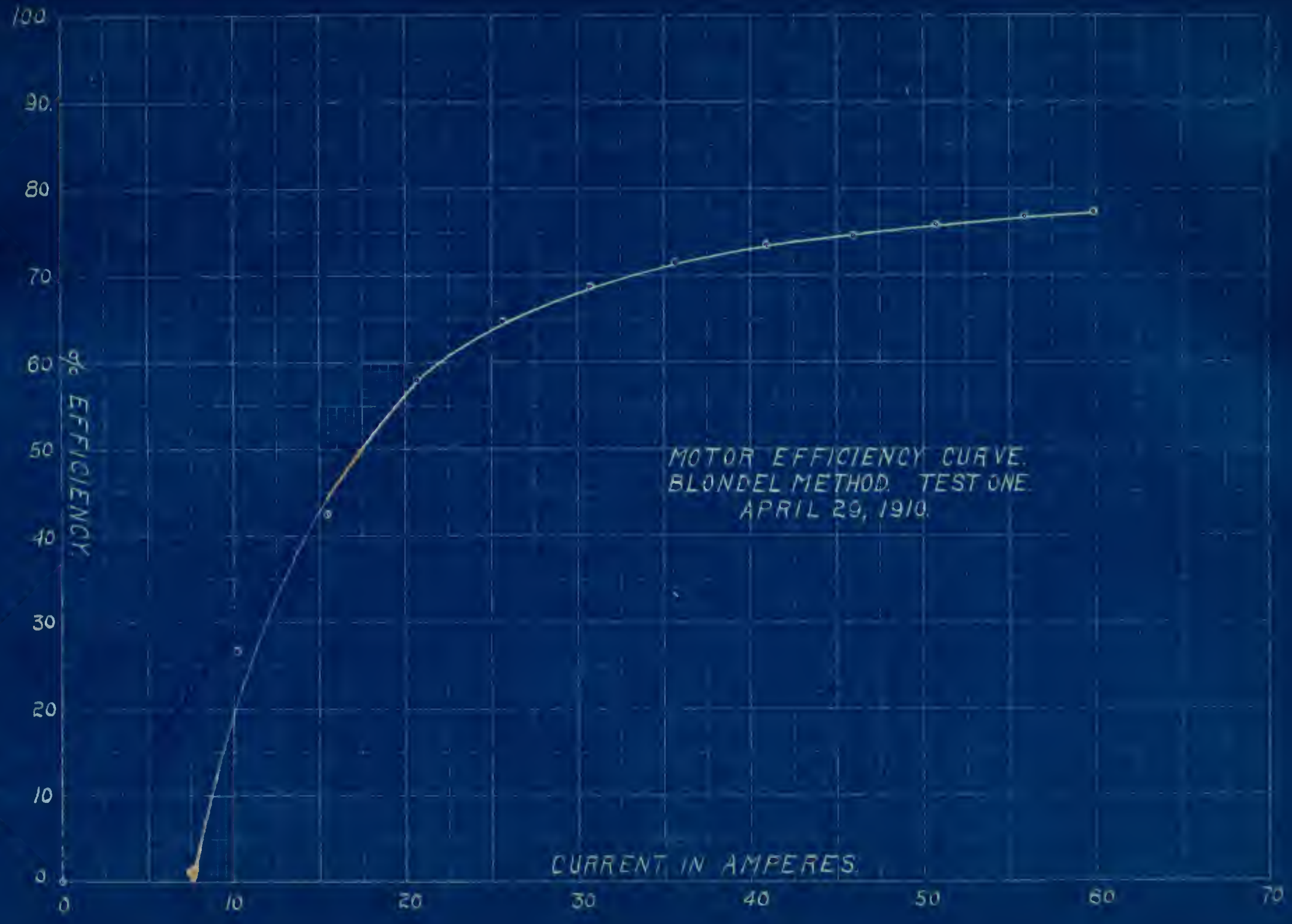
E'- Motor efficiency.



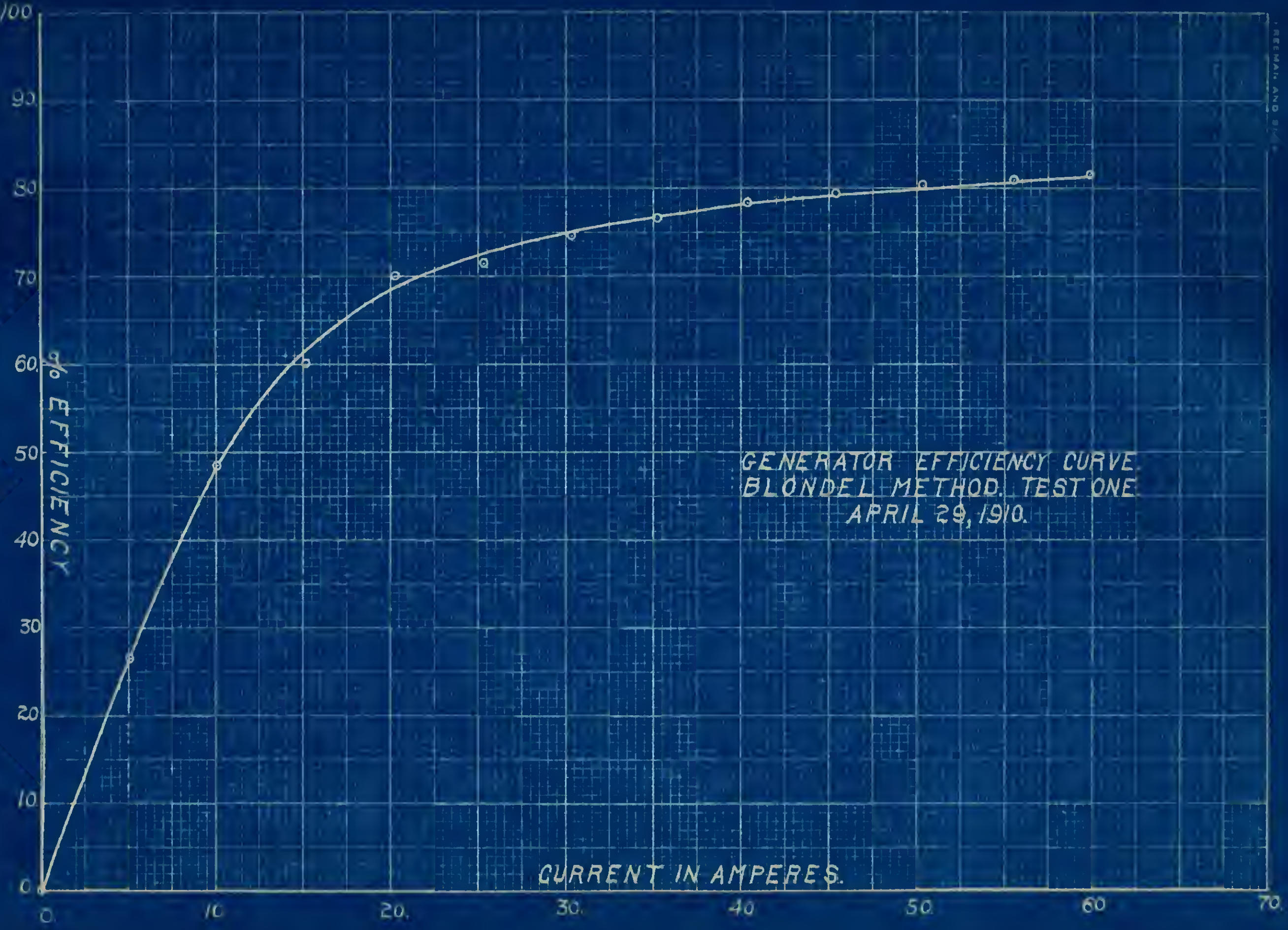
EFFICIENCY CURVE.
NORTHERN MOTOR.
BLONDEL METHOD. TEST ONE.
APRIL 29, 1910.



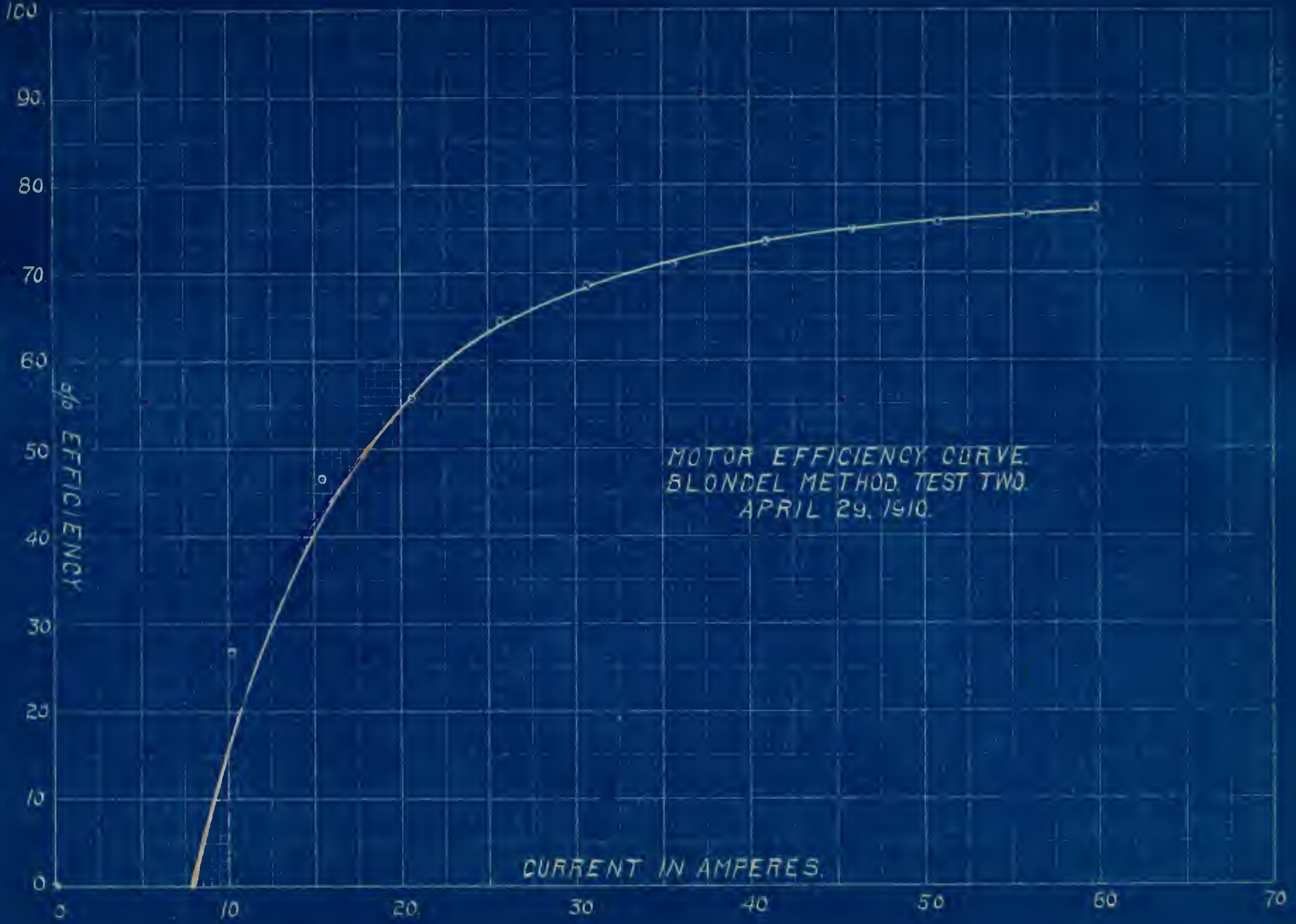
EFFICIENCY CURVE.
NORTHERN MOTOR.
BLONDEL METHOD. TEST TWO.
APRIL 29, 1910.



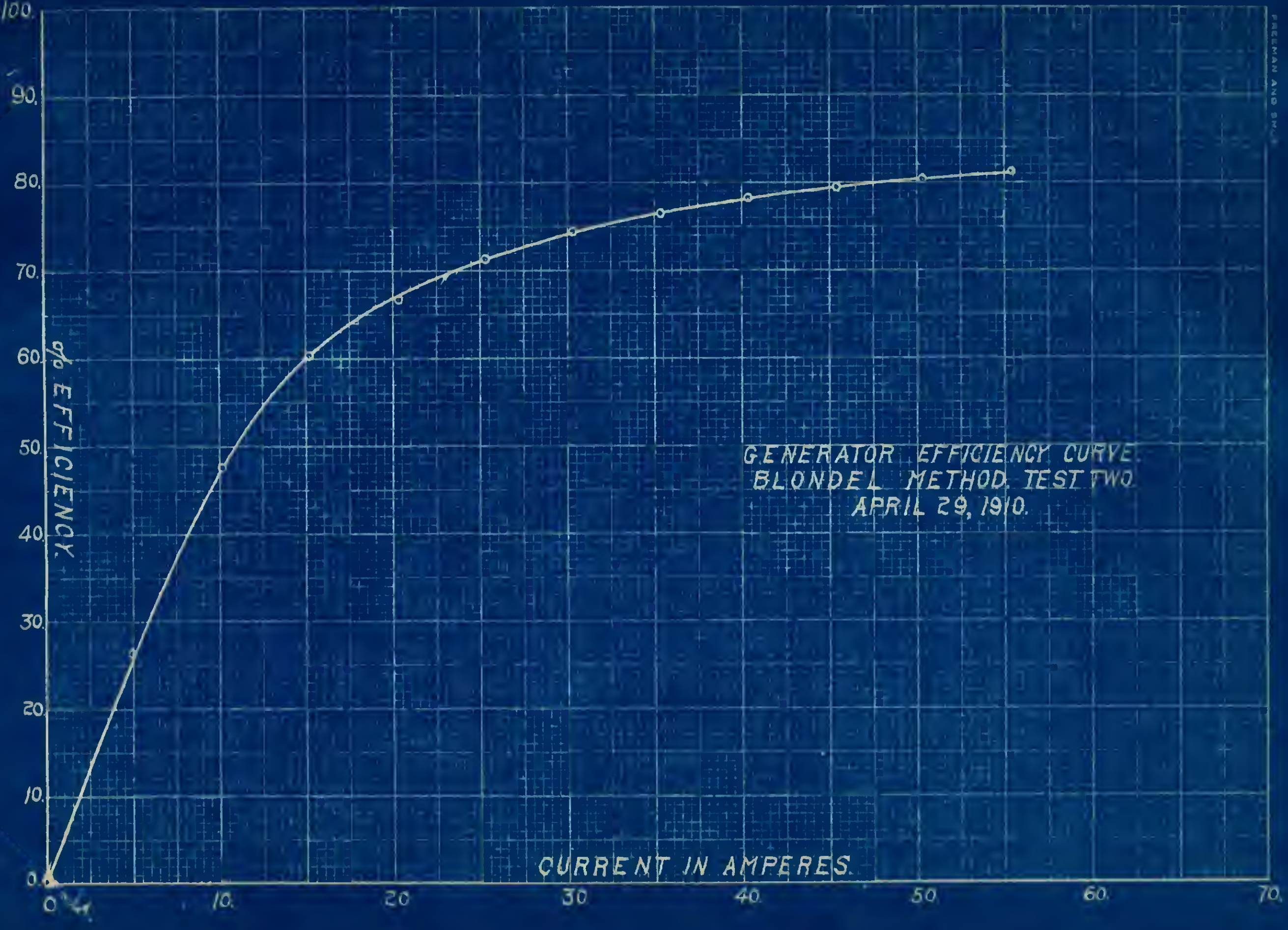
MOTOR EFFICIENCY CURVE.
BLONDEL METHOD. TEST ONE.
APRIL 29, 1910.



GENERATOR EFFICIENCY CURVE
BLONDEL METHOD. TEST ONE
APRIL 29, 1910.



MOTOR EFFICIENCY CURVE.
BLONDEL METHOD. TEST TWO.
APRIL 29, 1910.



GENERATOR EFFICIENCY CURVE
BLONDEL METHOD. TEST TWO.
APRIL 29, 1910.

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PART 7.

HOPKINSON'S OPPOSITION METHOD.

The scheme of connections for this method are as shown in the diagram on page 82. In this method the two like machines were connected both electrically and mechanically, so that power was supplied from the generator to the motor electrically and from the motor to the generator mechanically; the losses being supplied from a separate mechanical source. The three machines were brought up to speed by starting the auxiliary motor in the usual manner, the switch between the two test machines being open. The test generator and motor were in electrical opposition and their terminal voltages were made equal before the switch was closed between them. After this adjustment was made and the switch closed, an interchange of power between the motor and generator could be brought about by weakening the motor field and strengthening that of the generator. In this case the motor tended to speed up and drive the generator mechanically; the latter, in turn, having the higher voltage, drove the motor electrically.

For calculating the commercial efficiency of the motor we used the following equation.

$$\text{Com.Eff.} = \frac{IE_1 - (P_{a_1} + P_{f_1} + P_{s_1})}{I\,E_1}$$

For calculating the commercial efficiency of the generator we used the following equation.

$$\text{Com. Eff.} = \frac{I\,E_2}{I\,E_2 + P_{a_2} + P_{f_2} + P_{s_2}}$$

Where IE_1 = Power supplied to motor.

IE_2 = Power delivered by generator to motor.

P_{a_1} = I^2R loss in armature of motor.

P_{a_2} = I^2R loss in armature of generator.

P_{f_1} = I^2R loss in field of motor.

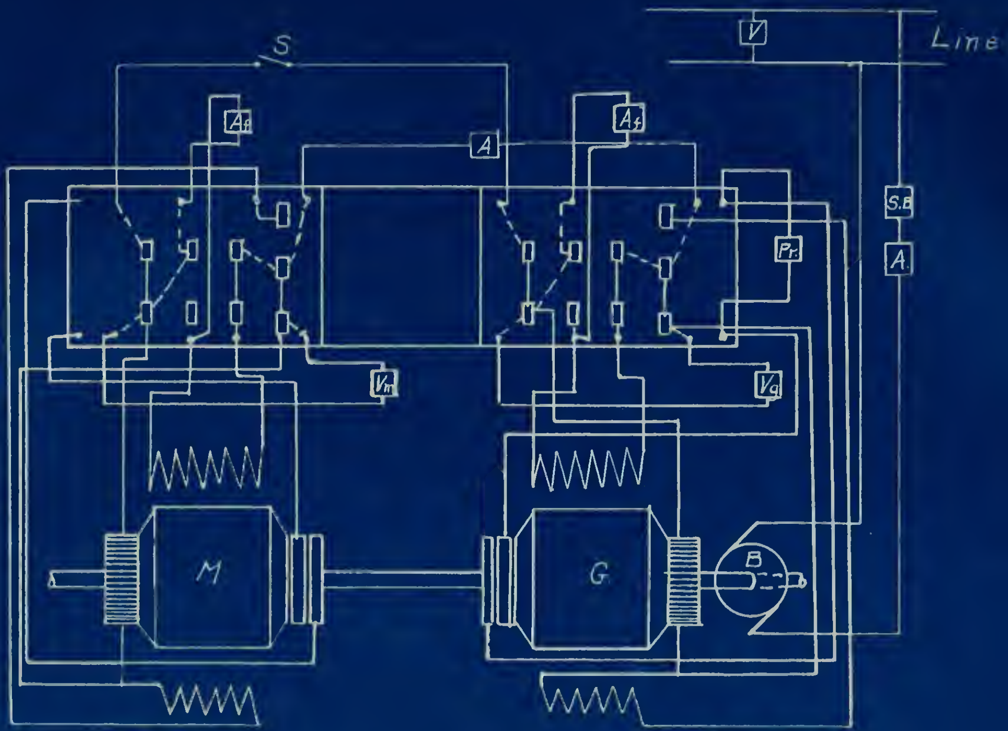
P_{f_2} = I^2R loss in field of generator.

P_{s_1} = stray power loss in motor.

P_{s_2} = stray power loss in generator.

P_B = power supplied by auxiliary motor.

$$P_{s_1} = P_{s_2} = \frac{P_B - (P_{a_1} + P_{a_2} + P_{f_1} + P_{f_2})}{2}$$



Connections for Hopkinson's Opposition Method

EXPERIMENTAL AND CALCULATED DATA.

HOPKINSON'S OPPOSITION METHOD. (Test One.) April 29, 1910.

I'	E	I	EI	P_s	P_a	P_f	E_m
2.16	105.3	0	000	711	0	220.9	0:0
1.99	106.0	5	530	696	2.9	188.3	36.59
1.90	105.0	10.2	1071	696	12.1	170.7	53.19
1.87	104.0	15.4	1602	705	27.5	165.1	63.25
1.83	104.0	20.6	2142	702	49.1	158.4	69.30
1.82	103.5	25.7	2660	679	76.6	156.6	73.45
1.75	103.0	30.7	3162	664	109.3	144.9	76.95
1.71	102.5	35.6	3649	662	146.9	138.1	78.45
1.71	102.0	40.9	4172	651	194.6	138.1	80.10
1.69	101.8	45.9	4654	639	244.3	135.3	81.40
1.66	100.9	50.8	5126	665	299.3	130.4	81.85
1.66	100.5	55.9	5618	618	362.3	130.4	82.90

I' - Motor field current.

E - .. armature voltage.

I - .. .. current.

EI - .. input.

P_s - Stray power loss.

P_a - Copper loss in armature.

P_f - .. .. .. field.

E_m - Commercial efficiency of the motor.

EXPERIMENTAL AND CALCULATED DATA.

HOPKINSON'S OPPOSITION METHOD. (Test One.) April 29, 1910.

I'	E	I	EI	P_s	P_a	P_f	E_g
2.18	107.3	0	000	711	0.0	225.4	0.0
2.16	106.3	5	532	696	2.8	221.8	36.59
2.12	105.7	10.2	1078	696	11.8	213.5	53.90
2.11	105.1	15.4	1619	705	26.8	211.2	63.25
2.10	104.8	20.6	2159	702	47.9	209.5	69.30
2.09	104.0	25.7	2673	679	74.6	207.3	73.45
2.09	103.9	30.7	3190	664	106.5	207.3	76.95
2.08	103.3	35.6	3678	662	143.2	205.7	78.45
2.06	103.1	40.9	4217	651	189.1	201.4	80.10
2.05	102.8	45.9	4719	639	238.1	199.5	81.40
2.05	102.3	50.8	5197	665	291.7	199.5	81.85
2.05	102.1	55.9	5707	818	353.1	199.5	82.90

I'- Generator field current.

E - .. armature voltage.

I - .. .. current.

EI - .. output.

P_s- Stray power loss.

P_a- Copper loss in armature.

P_f- .. .. .. field.

E_g- Commerical efficiency of the generator.

EXPERIMENTAL AND CALCULATED DATA.

HOPKINSON'S OPPOSITION METHOD. (Test Two.) April 29, 1910.

I'	E	I	EI	P_s	P_a	P_f	E_m
2.11	105.3	0	000	684	0	210.5	0.0
1.99	106.4	5	532	693	2.9	188.3	34.80
1.94	105.3	10.2	1074	709	12.1	177.8	53.80
1.89	104.8	15.4	1614	704	27.5	169.0	63.40
1.86	104.0	20.6	2142	699	49.1	163.7	69.45
1.82	103.2	25.7	2662	692	76.6	156.6	73.65
1.79	103.0	30.7	3162	701	109.3	151.6	76.25
1.79	102.5	35.6	3649	699	146.9	151.6	78.10
1.74	102.5	40.9	4192	656	194.0	143.3	80.10
1.82	102.0	45.9	4682	662	244.3	140.0	81.25
1.69	101.5	50.8	5156	632	299.3	135.3	82.40
1.66	100.5	55.9	5618	618	362.3	130.4	82.90

I'- Motor field current.

E - .. armature voltage.

I - .. .. current.

EI - .. input.

P_a- Copper loss in armature.

P_f- .. .. .. field.

P_s- Stray power loss.

E_m- Commercial efficiency of the motor.

EXPERIMENTAL AND CALCULATED DATA.

HOPKINSON'S OPPOSITION METHOD. (Test Two.) April 29, 1910.

I'	E	I	EI	P_s	P_a	P_f	E_g
2.17	107.6	0	000	684	0.0	223.5	0.0
2.16	107.2	5	536	693	2.8	221.8	34.50
2.12	106.3	10.2	1084	709	11.8	213.5	53.80
2.11	105.7	15.4	1628	704	26.8	221.2	63.40
2.11	105.3	20.6	2169	699	47.9	211.2	69.45
2.10	104.8	25.7	2693	692	74.6	209.5	73.65
2.09	104.1	30.7	3196	701	106.5	207.4	76.25
2.09	104.0	35.6	3702	699	143.2	207.3	78.10
2.09	103.9	40.9	4250	665	189.1	207.3	80.10
2.06	103.4	45.9	4736	662	238.1	201.4	81.25
2.06	103.0	50.8	5232	632	291.7	201.4	82.40
2.05	102.1	55.9	5707	618	353.1	199.5	82.90

I'- Generator field current.

E - .. armature voltage.

I - .. .. current.

EI - .. output.

P_s- Stray power loss.

P_a- Copper loss in armature.

P_f- .. .. .. field.

E_g- Commercial efficiency of the generator.

HOPKINSON'S OPPOSITION METHOD. (Test One.) April 29, 1910.

Efficiency of the Northern Motor.

I	E	EI	P	E'
22.1	107.2	2369	519.6	78:1
21.7	107.2	2326	515.9	77.85
21.6	107.2	2315	515.0	77.8
22.0	107.2	2358	518.6	78.1
22.1	107.2	2369	519.6	78.1
22.3	107.2	2391	520.9	78.3
22.7	107.2	2433	525.2	78.4
23.2	107.2	2487	529.9	78.8
23.9	107.2	2562	536.8	79.0
24.6	107.2	2637	543.8	79.5
25.3	107.2	2712	551.1	79.7
26.5	107.2	2841	564.0	80.3

I - Armature current.
E - Motor voltage.
EI - Motor input.
P - Losses.
E'- Motor efficiency.

HOPKINSON'S OPPOSITION METHOD. (Test Two.) April 29, 1910.

Efficiency of the Northern Motor.

I	E	EI	P	E'
21.6	107.2	2315	515.1	77.8
21.6	107.2	2315	515.1	77.8
21.9	107.2	2348	517.6	78.0
22.0	107.2	2358	518.6	78.2
22.2	107.2	2380	520.5	78.2
22.6	107.2	2423	524.2	78.4
23.4	107.2	2508	532.0	78.8
24.1	107.2	2584	538.8	79.2
24.3	107.2	2605	540.7	79.3
25.1	107.2	2691	549.0	79.7
25.6	107.2	2744	554.2	79.9
26.5	107.2	2841	564.0	80.3

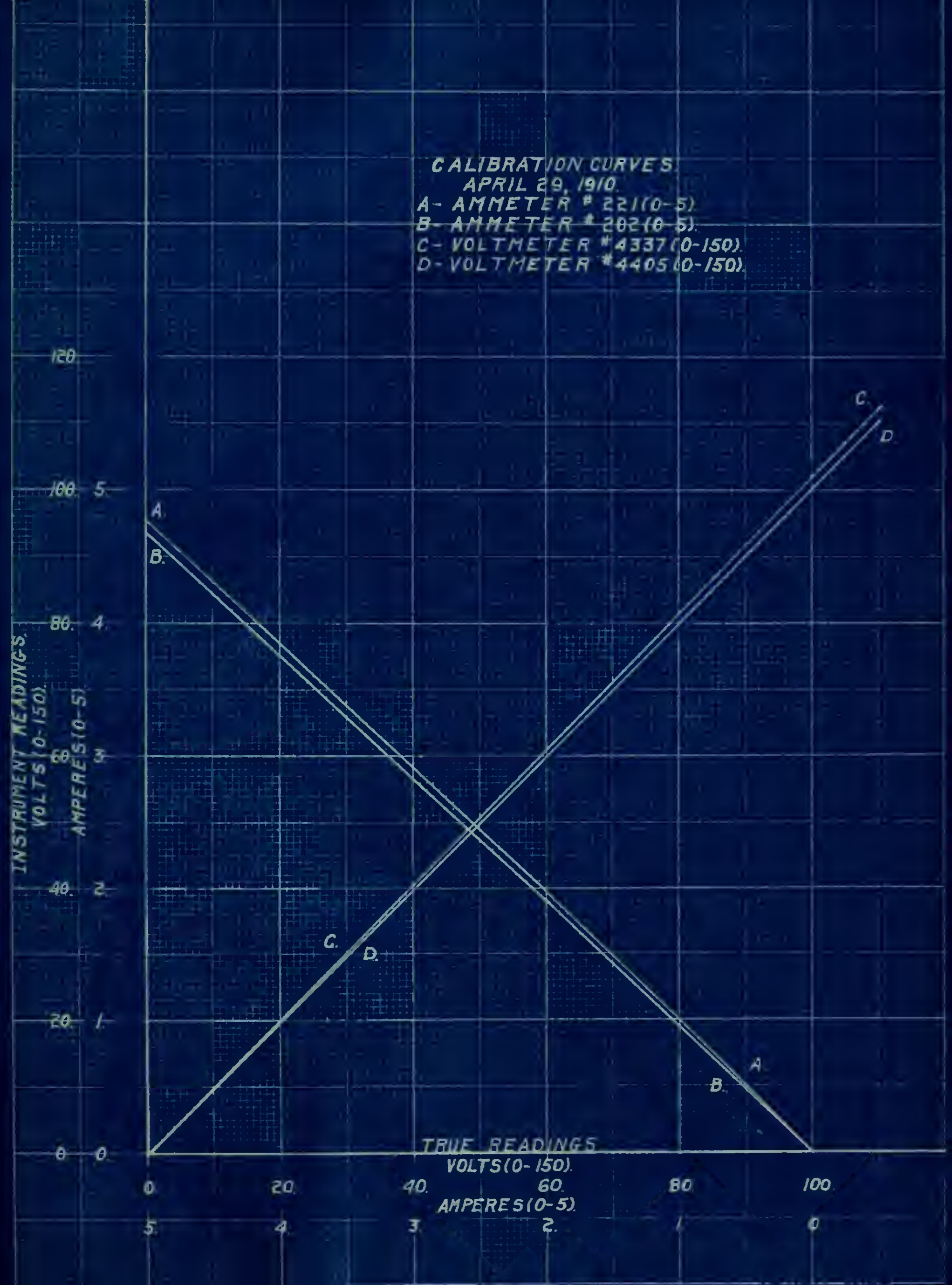
I - Armature current.

E - Motor voltage.

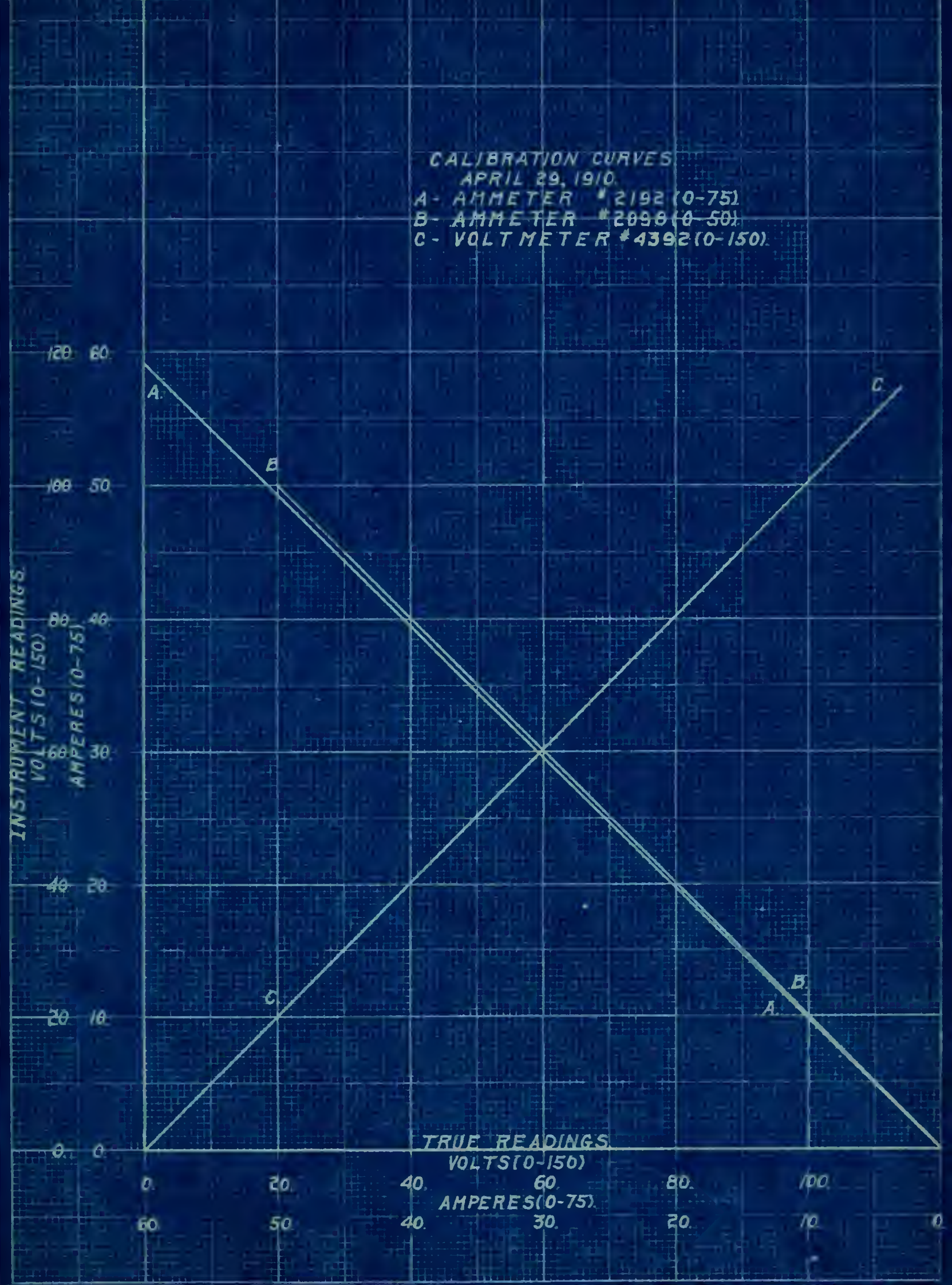
EI - Motor input.

P - Losses.

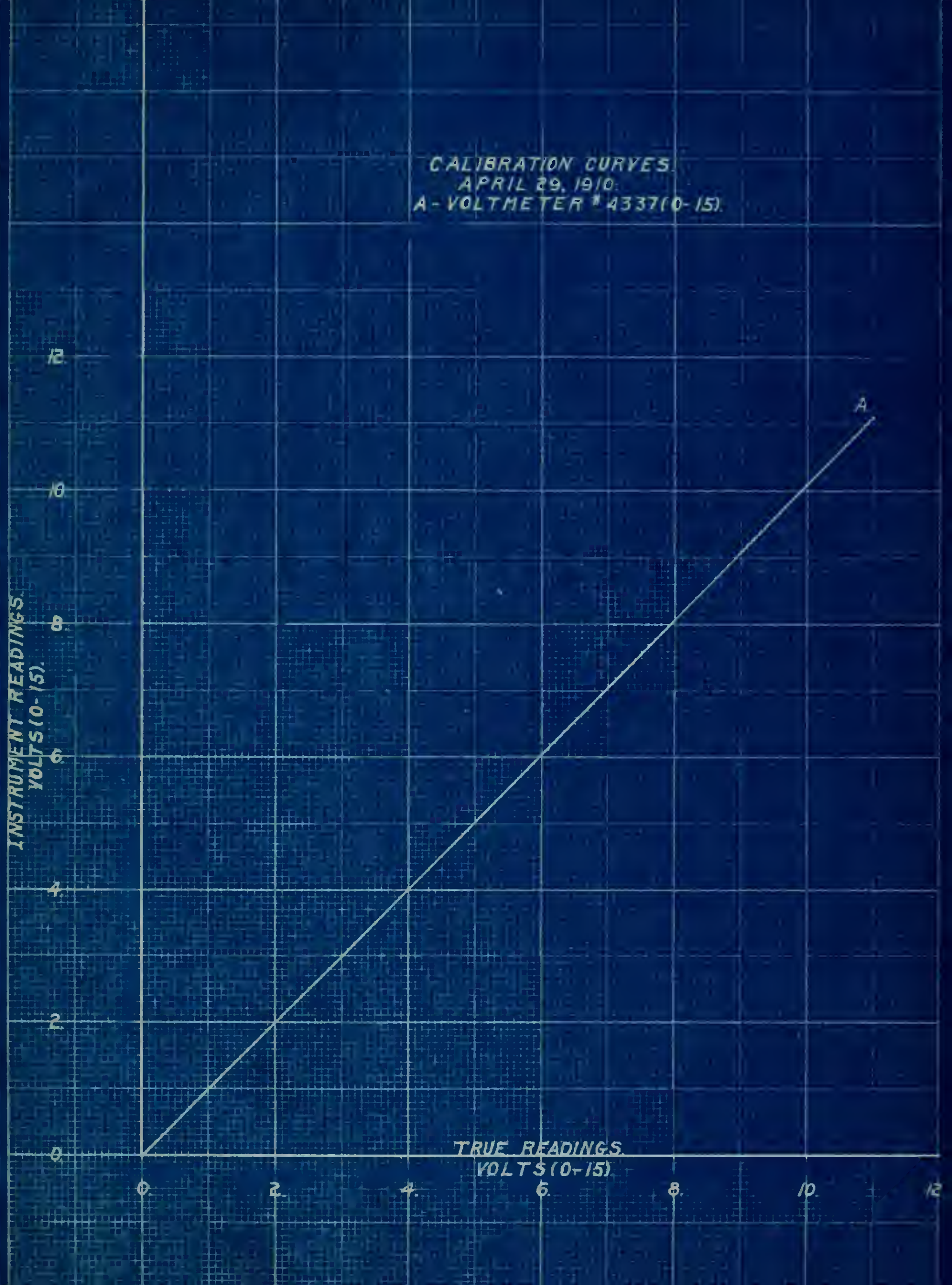
E' - Motor efficiency.



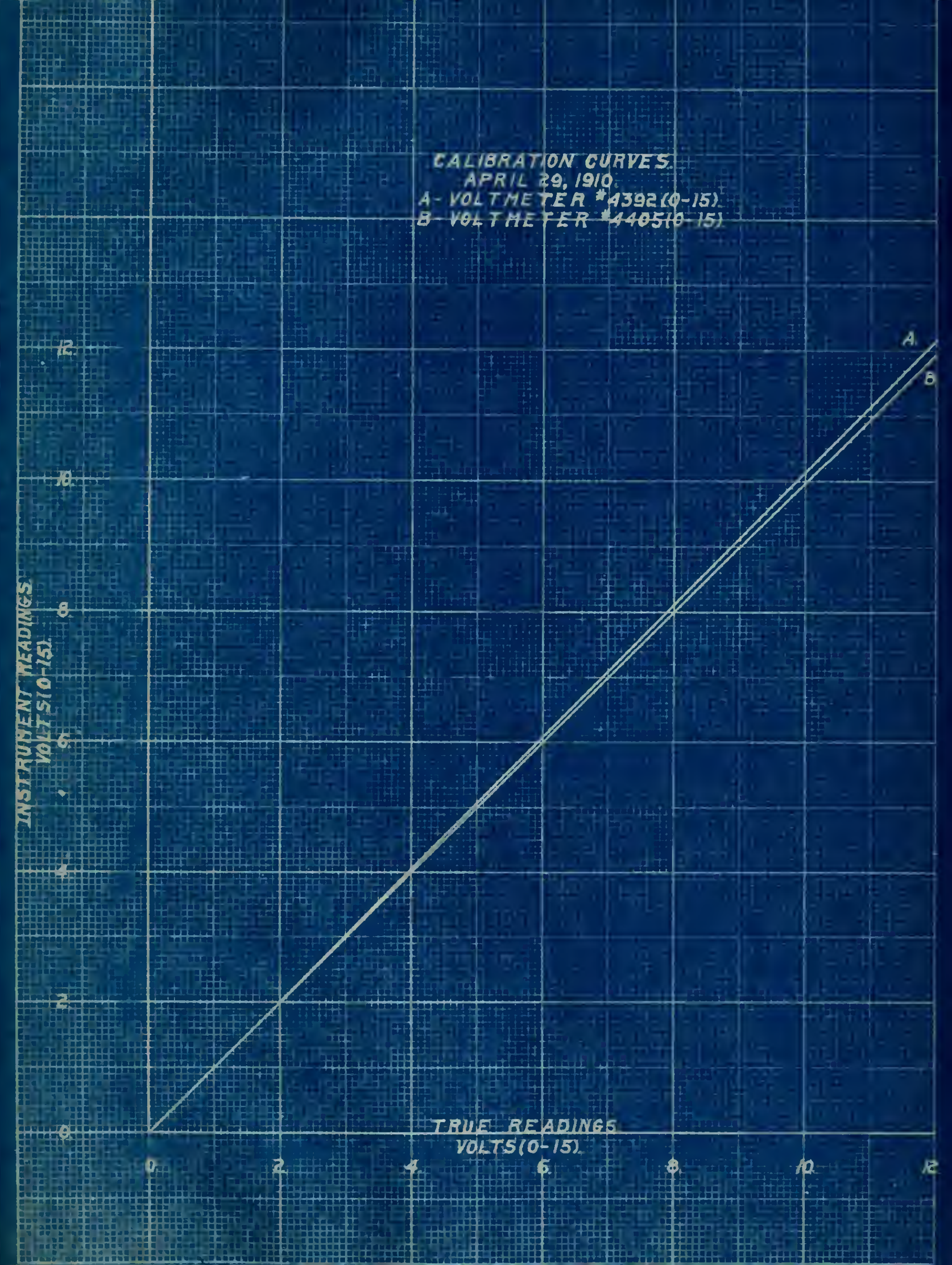
CALIBRATION CURVES.
APRIL 29, 1910.
A- AMMETER # 221 (0-5).
B- AMMETER # 202 (0-5).
C- VOLTMETER #4337 (0-150).
D- VOLTMETER #4405 (0-150).



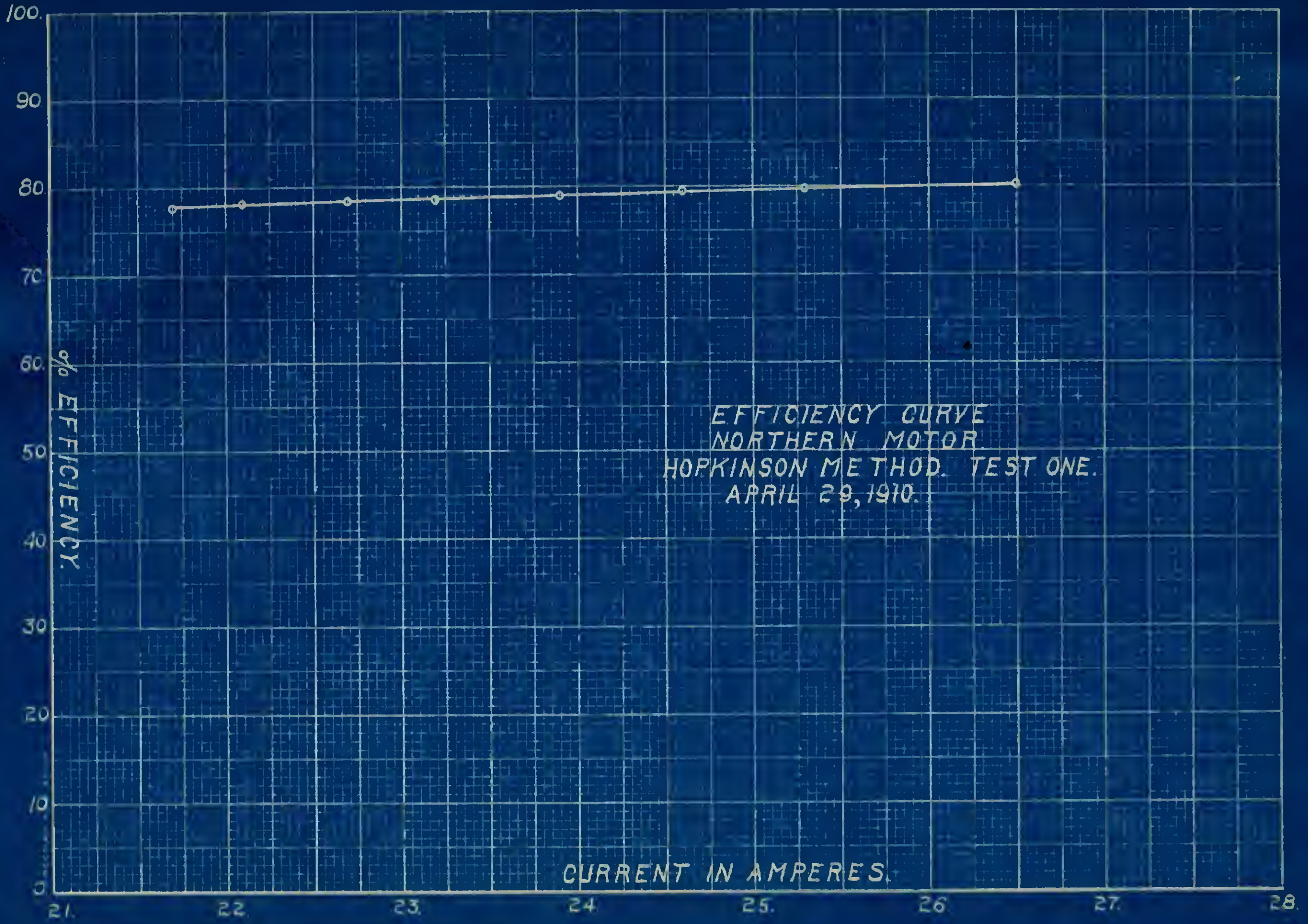
CALIBRATION CURVES
APRIL 29, 1910.
A- AMMETER #2192 (0-75)
B- AMMETER #2098 (0-50)
C- VOLTMETER #4392 (0-150).



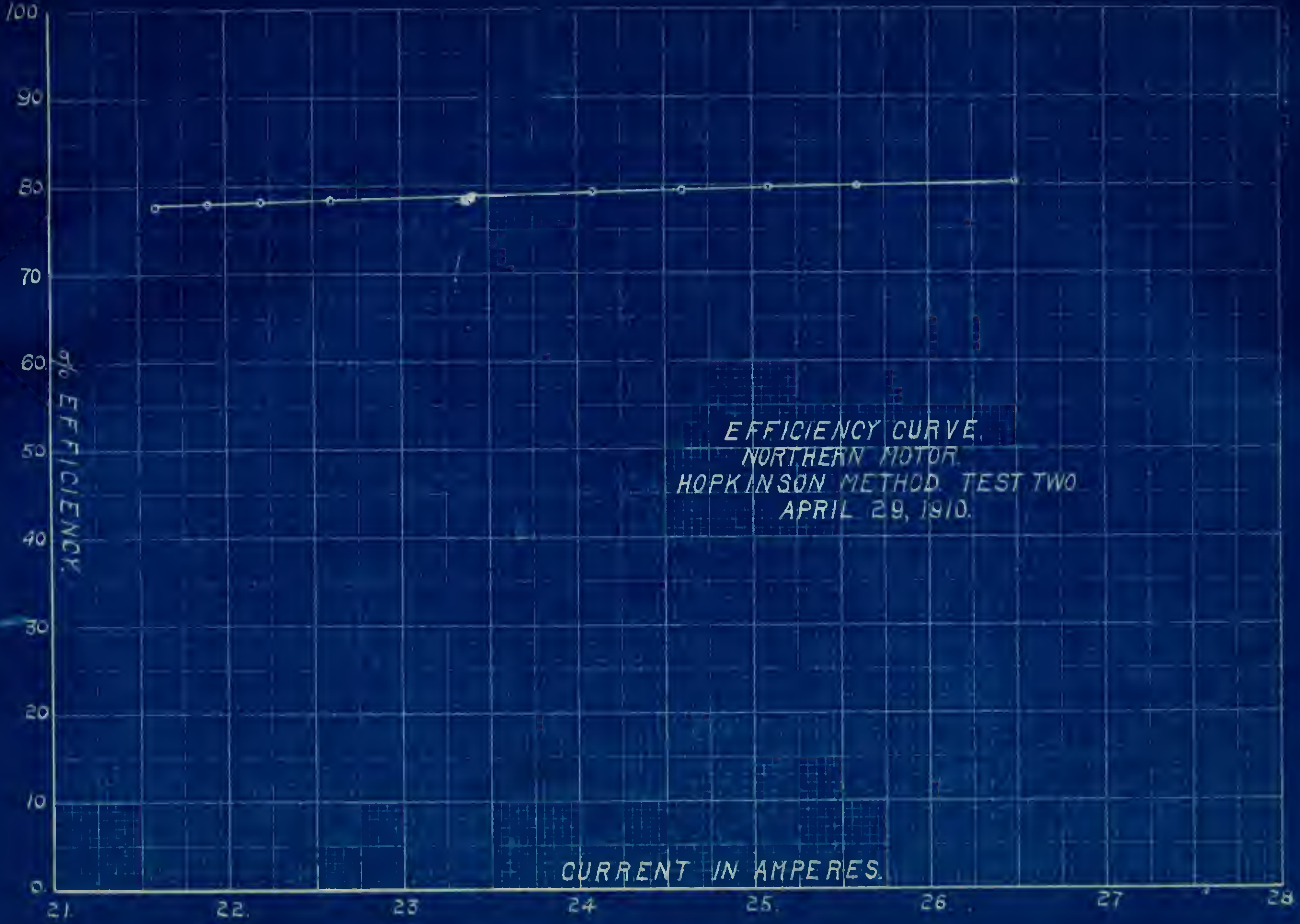
CALIBRATION CURVES.
APRIL 29, 1910.
A - VOLTMETER # 4337 (0-15).



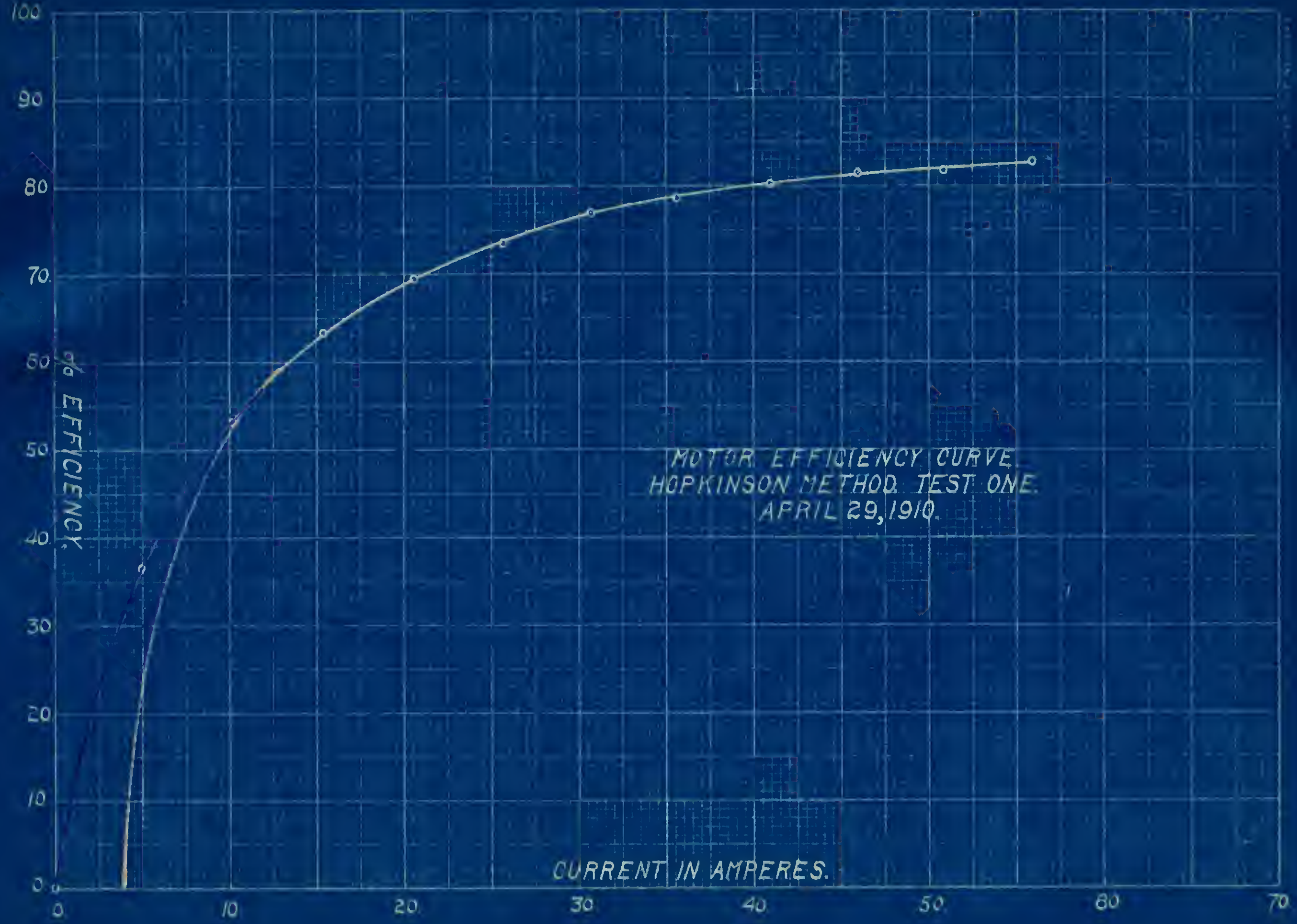
CALIBRATION CURVES.
APRIL 29, 1910.
A- VOLTMETER #4392 (0-15).
B- VOLTMETER #4405 (0-15).

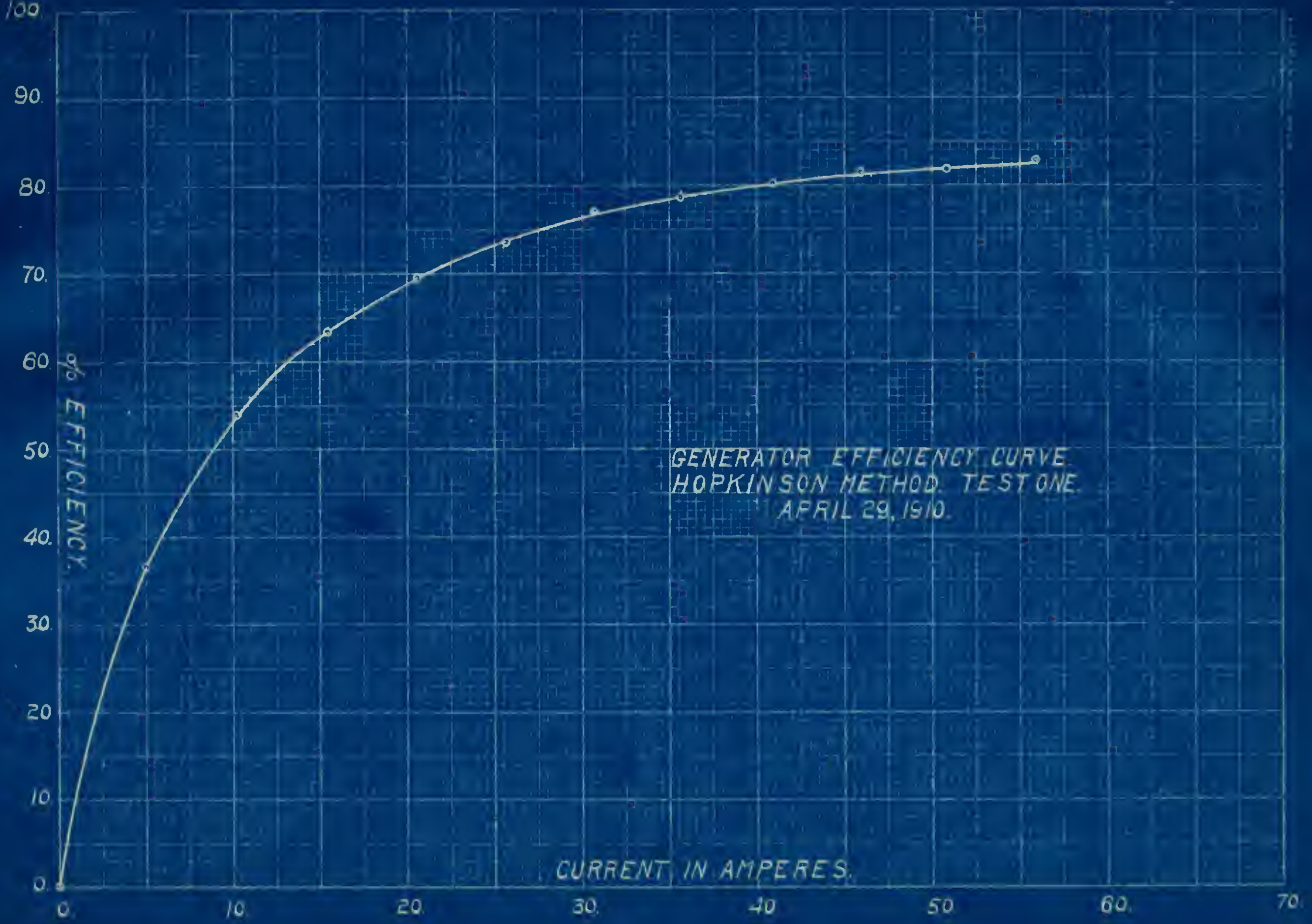


EFFICIENCY CURVE
NORTHERN MOTOR
HOPKINSON METHOD. TEST ONE.
APRIL 29, 1910.

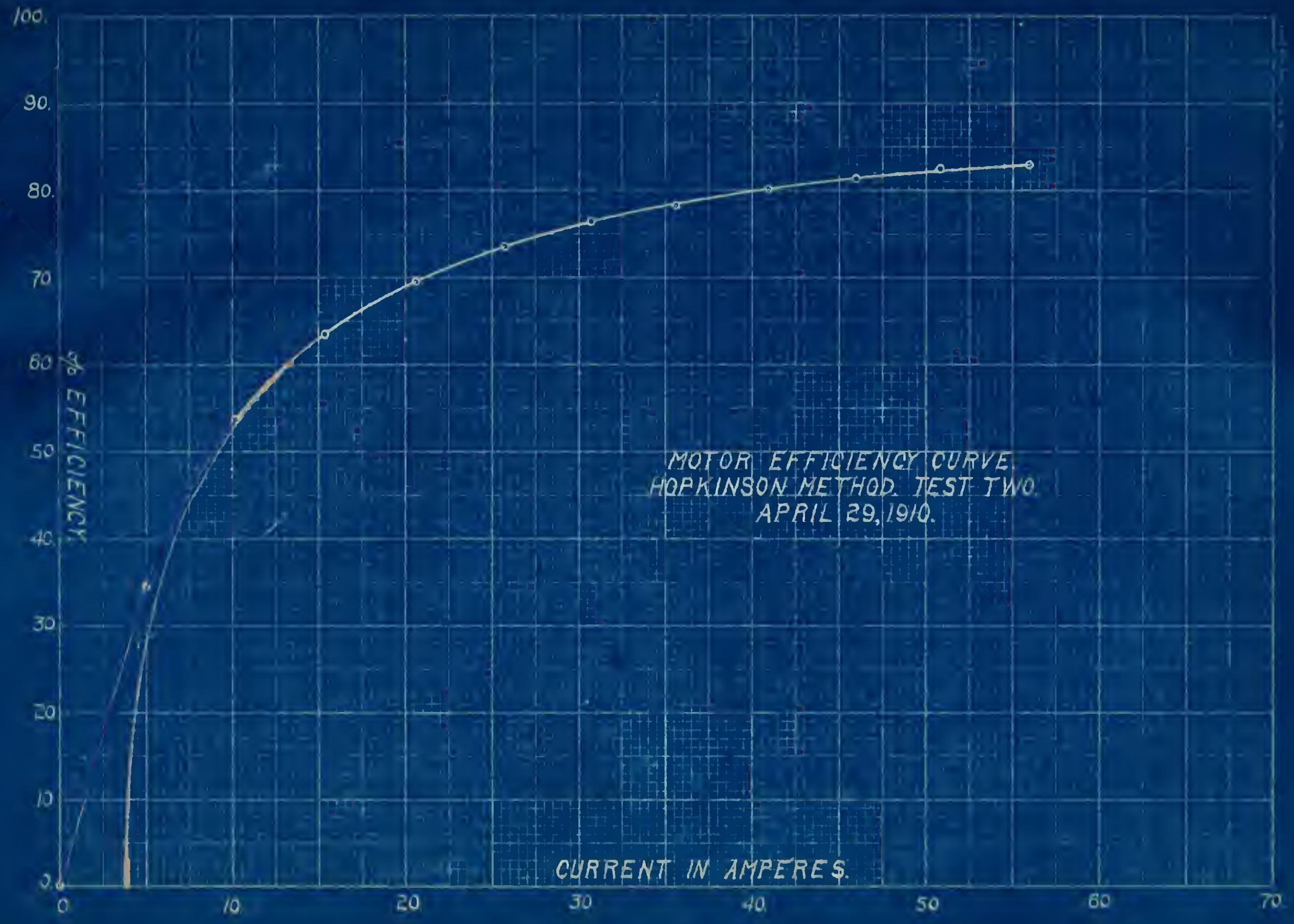


EFFICIENCY CURVE.
NORTHERN MOTOR.
HOPKINSON METHOD. TEST TWO.
APRIL 29, 1910.

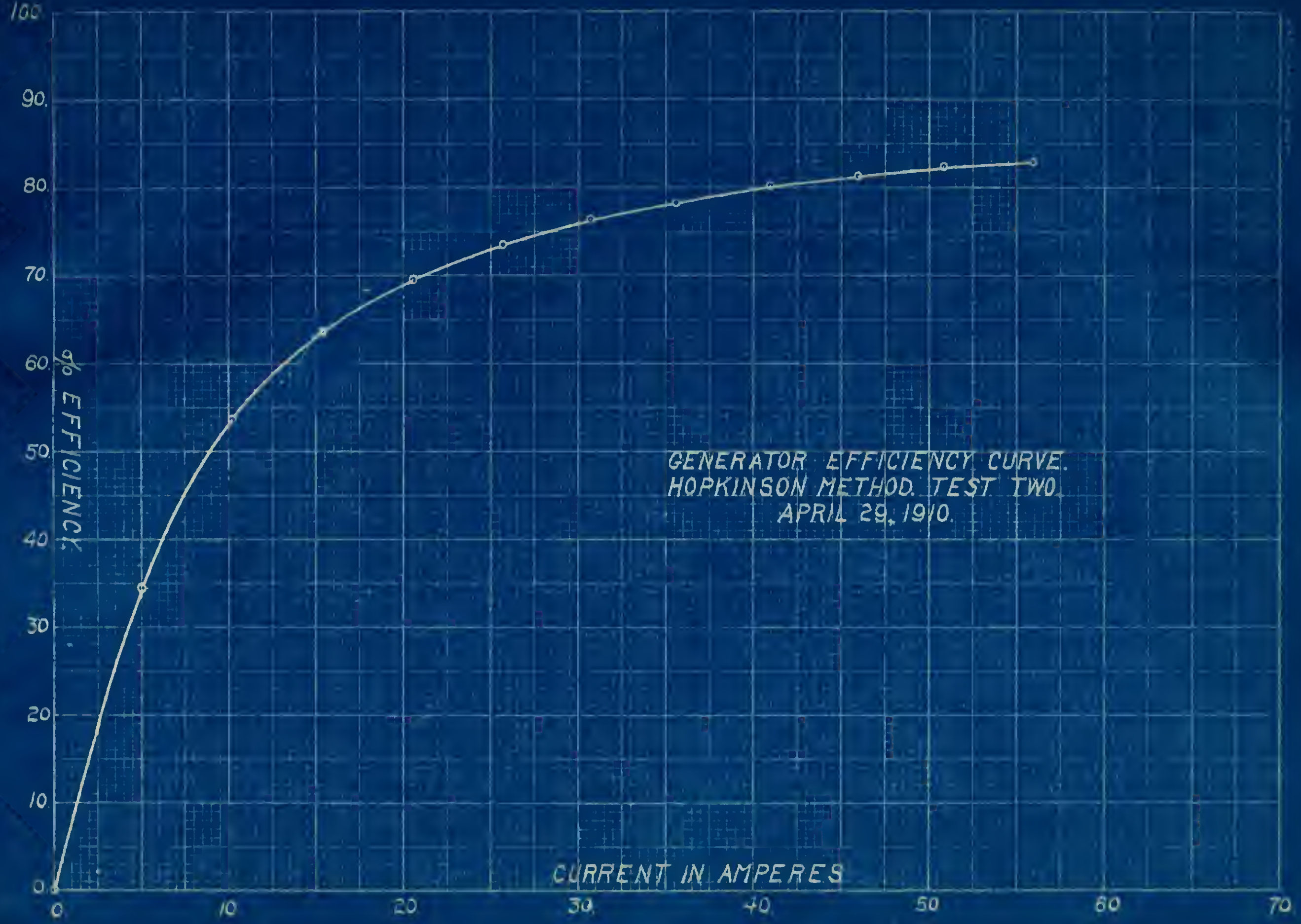

MOTOR EFFICIENCY CURVE
HOPKINSON METHOD TEST ONE.
APRIL 29, 1910.



GENERATOR EFFICIENCY CURVE
HOPKINSON METHOD. TEST ONE.
APRIL 29, 1910.



MOTOR EFFICIENCY CURVE.
HOPKINSON METHOD. TEST TWO.
APRIL 29, 1910.



GENERATOR EFFICIENCY CURVE.
HOPKINSON METHOD. TEST TWO.
APRIL 29, 1910.

PART 8.

CONCLUSION.

In the Prony brake method on this set it was rather difficult to obtain very accurate results due to the high speed and small capacities of the machines. The capacities of the machines being small the differences in the scale readings with changes in load were also rather small. A slight error ~~error~~ therefore, in obtaining the weight would probably produce a considerable error in the efficiency. Also due to the high speed of the machines considerable heat was produced in the pulley which effected the friction and made it rather difficult to obtain readings on the scale. It can be seen from the curves on pages 16 and 17 that the efficiency obtained by this method was higher than that obtained by the other methods with the exception of Kapp's.

The losses in an electric machine, whether running as a motor or a generator, can be subdivided into three classes:

(1) Copper losses in the armature and field circuits.

(2) Iron losses.

(a) Hysteresis loss.

(b) Eddy current loss.

(3) Mechanical losses.

(a) Bearing friction.

(b) Brush friction.

(c) Windage.

The copper loss need not be determined experimentally; it is only necessary to measure the resistance of the windings; and calculate the I^2R loss for any desired value of current. The iron loss in any machine depends upon the magnetic flux and upon the speed. In a shunt wound machine the flux is constant as long as the field current is constant. The brush friction and the windage losses depend upon speed only. The bearing friction is constant in a direct connected machine. It is customary to assume the iron and friction losses in a shunt wound machine as constant at all loads. This method of figuring efficiency from losses is not quite correct, for the reason that the speed does not remain altogether constant at all loads, but may drop a few per cent between no load and full load.

As can be seen from the curves on pages 31, 32, 33 and 34 the efficiency as obtained by the stray power method is lower than that obtained by any other method.

The Bondel opposition method is theoretically the most rational, because the electrical loss is supplied electrically, while the mechanical losses are supplied mechanically; its disadvantage is that it requires a booster and an auxiliary motor. Omitting the booster and supplying all the losses gives Hopkinson's Method; this method is not as good as Blondel's, in that it gives only approximate results for efficiency. Omitting the auxiliary motor in the Blondel method gives the Kapp and Hutchinson Method. In these tests all the losses are supplied electrically, either by a booster or directly from the line, or by both methods.

The absolutely correct method of these two is that of Hutchinson, in which the copper loss is supplied by the booster and the iron loss plus the friction is supplied from the line. Kapp's method omits the booster and supplies all losses from the line.

This method gives only approximate results for efficiency. In Hopkinson's method since the two machines are nearly equally loaded it may be assumed that their efficiencies for any particular value of current are equal. This is not strictly so, as the motor will be loaded to a greater extent than the generator, and the excitation of the generator will be greater than that of the motor. The theoretically correct method for determining efficiency is that of Hutchinson, where the losses are supplied partly in series, and partly in parallel.

The advantage of the opposition methods over the Prony brake and Stray Power methods is that large machines can be tested at all loads without taking heavy currents from the supply mains. This is sometimes a matter of great importance. Although of very great practical use, the Hopkinson test has the disadvantage that the fields of the machines are unequally excited, and consequently the iron losses are not equal in the two machines and are not of the normal value in the case of the motor.

The test proposed by Hopkinson was for large machines and with such machines the results obtained are quite satisfactory. With small machines two factors interfere seriously with the accuracy of the results. In the case of small machines, the current taken by the motor in driving the generator when the latter is giving no current is a considerable fraction of the normal full load current of the motor. Thus the machines are never even approximately equally loaded, the motor having always a much heavier output. The machines thus do not work on the same part of the efficiency curve; and although they might have the same efficiency when working at the same load, it is not correct to assume that they have the same efficiency when one is driving the other. For the same reasons it is necessary with small machines to produce a relatively great difference in the field strength of motor and generator in order that the motor may give the necessary output required to overcome the no load losses. With small machines the working conditions cannot therefore be considered to be normal as regards the losses of the machines.

In our testing we found Potier's method impossible to perform on this set due to the fact that the field of the motor must be stronger than that of the generator which was not true in this case. The field of the motor must be stronger than that of the generator in order to give it an additional torque for overcoming the iron and friction losses of the set.

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